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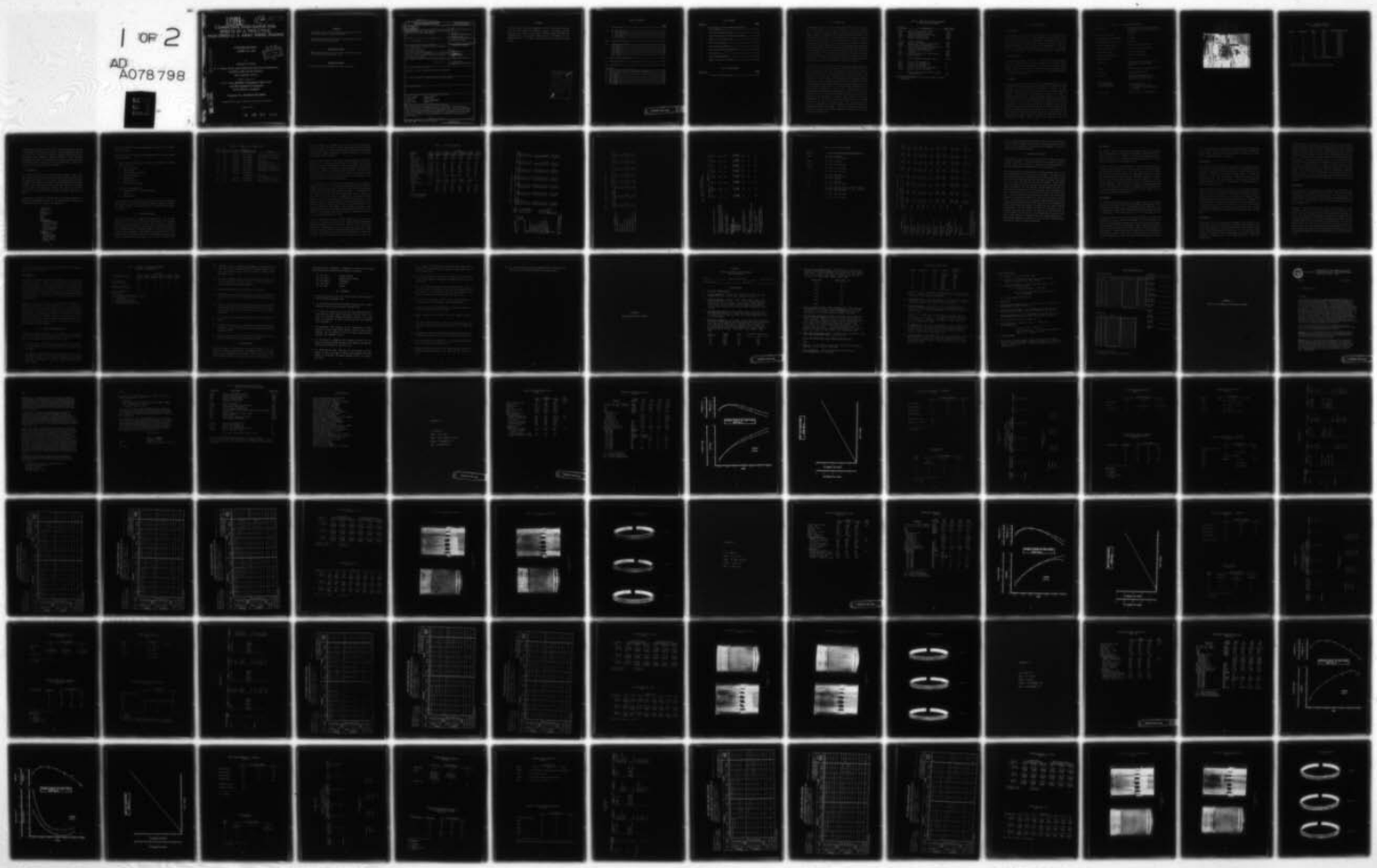

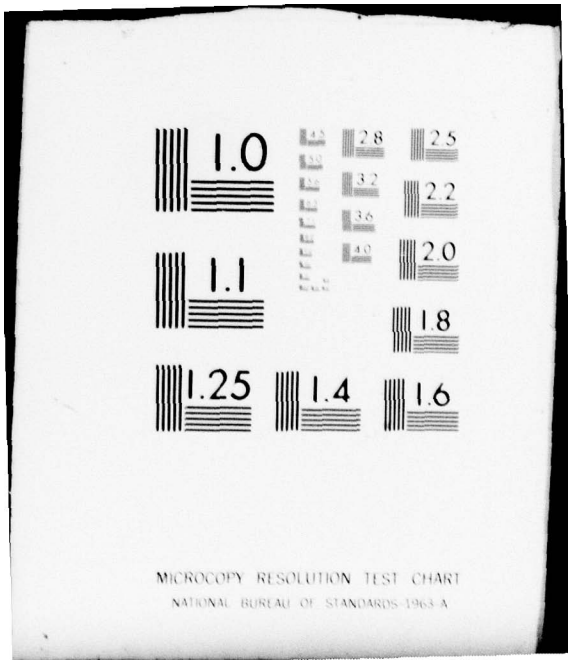
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COMBATING HIGH-SULFUR FUEL EFFECTS IN A TWO-CYCLE, HIGH-SPEED U. S. ARMY DIESEL ENGINE

INTERIM REPORT
AFLRL No. 109

by

Edwin A. Frame

U. S. Army Fuels and Lubricants Research Laboratory
Southwest Research Institute
San Antonio, Texas

Under contract to

U. S. Army Mobility Equipment Research and Development Command
Fort Belvoir, Virginia

Contract No. DAAK70-78-C-0001

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August 1979

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Engine Wear	Engine Oils

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Six lubricants were evaluated for their effectiveness in controlling the deleterious effects of using high sulfur diesel fuel. Two of the lubricants gave significant improvement in the condition of some engine areas; however, none of the engine oils tested would allow the continuous use of high sulfur fuel with no penalty in engine condition as compared to the use of low sulfur fuel.

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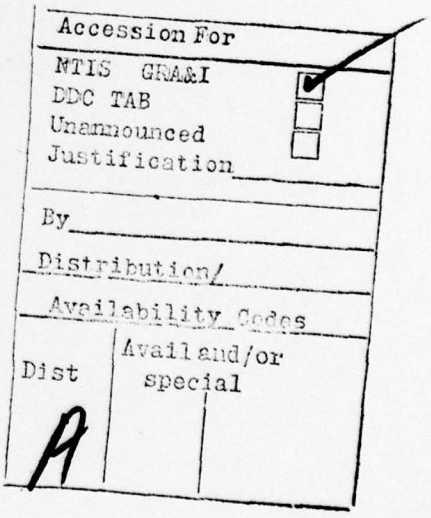
FOREWORD

The work reported herein was conducted at the U.S. Army Fuels and Lubricants Research Laboratory (USAFLRL), located at Southwest Research Institute, San Antonio, Texas under Contracts DAAG53-76-C-0003 and DAAK70-78-C-001. The contract monitor was Mr. F.W. Schaekel of USAMERADCOM, and Mr. T. C. Bowen of the same office was project technical monitor.



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I. INTRODUCTION

A significant portion of the U.S. Army Combat/Tactical Fleet is powered by a single family of high output two-stroke cycle diesel engines. Table 1 gives a listing of vehicles using this engine family. The engine manufacturer recommends using diesel fuels with less than 0.5 wt% sulfur because "too high a sulfur content results in excessive cylinder wear due to acid build-up in the lubricating oil" (Ref-1). Previous investigations conducted by the United States Army Fuels and Lubricants Research Laboratory (USAFLRL) which used an aluminum block engine model 6V53T, revealed engine/fuel/lubricant incompatibilities when using fuels containing greater than 0.5 wt% sulfur and MIL-L-2104C (Ref-2) specification lubricants. The observed incompatibilities included catastrophic piston/ring/exhaust valve failure and relatively high deposit and wear rates (Ref-3). Additional documentation of the detrimental effects of high sulfur diesel fuel can be found in references 4 through 11.

Outside CONUS, the U.S. Army must at times use diesel fuels which contain up to 0.7 wt% sulfur as allowed by VV-F-800b, OCONUS (Ref-12) and even higher sulfur levels may be encountered in the future. Based on the fuel sulfur limit allowed OCONUS and the previous USAFLRL test results with two-cycle diesel engine and high sulfur fuel, a program was initiated to identify methods of counteracting the detrimental effects of high sulfur fuel. The program objective was to identify fuel and/or lubricant modifications which would allow continous operation on diesel fuel containing greater than 0.7 wt% sulfur without significantly reducing engine performance or service life. Identification of such fuel/lubricant modifications would expand the supply of diesel fuel available to the U.S. Army and potentially extend the service life of two-cycle diesel equipment. A previous report (Ref-13) covered the establishment of low and high sulfur fuel baselines using a constant lubricant in the iron block engine model 3-53. The current report covers the evaluation of various lubricants for their effectiveness in combating high sulfur fuel effects. Lubricant effectiveness was defined in terms of how well the lubricant performed as compared to the low and high sulfur fuel baselines.

TABLE 1. ARMY TACTICAL VEHICLES POWERED
BY TWO-CYCLE DIESEL ENGINES

Designation	Description	Engine Model
M106A1	Mortar, Self-propelled. 107mm	6V53
M107	Gun, Self-propelled. 175mm	8V71T
M108	Howitzer. Self-propelled. 105mm	8V71T
M109	Howitzer. Medium. 155mm	8V71T
M110	Howitzer. Self-propelled	8V71T
M113A1	Carrier. Personnel	6V53
M125A1	Mortar. Self-propelled. Full-tracked	6V53
M132A1	Flame Thrower. Self-propelled	6V53
M548	Carrier. Cargo. Tracked. 3442 kg(6-ton)	6V53
M551	Armored Reconnaissance/Airborne Assault Vehicle (Sheridan)	6V53T
M561	Gamma Goat	3-53
M557A1	Carrier. Command Post. Light Tracked	6V53
M578	Recovery Vehicle	8V71T
M746	Heavy Equipment Transporter (Het 70)	12V71T
XM667	Carrier. GM. Equipment. SP	a
XM727	Carrier. GM. Equipment. SP	a
XM730	Carrier. GM. Equipment. SP	a
XM741	Chassis, Gun, AA Artillery, 20mm, SP	a
XM806E1	Recovery Vehicle. FT Armored	a
---	Truck, Dump, 18 140 kg (20-ton), Diesel Electric Driven	6V71

a = Vehicles are powered by either 6V53, 6V53T, or 8V71T (TB-750-652)

II. EVALUATION DETAILS

A. Test Engine

An iron-block, two-cycle diesel engine Model 3-53 was utilized as the test engine. This engine is the powerplant used in the M561 1-1/4T tactical truck (Gamma Goat). Additionally, this engine was used to minimize test fuel and engine rebuild costs per test while utilizing a "real-world" engine. Table 2 gives the characteristics of the 3-53 engine. The engine was fully instrumented and coupled to a laboratory test stand dynamometer. Figure 1 shows the test cell installation.

B. Test Technique

All tests were conducted using the U.S. Army 210-hour wheeled-vehicle test cycle (Ref-14) which has been correlated to 32,200 km (20,000 miles) of proving ground operation. This test cycle includes alternating periods of full-power and cold idling with an overnight shutdown as shown in Table 3. A complete description of the detailed procedure is presented in Appendix A.

C. Approach

As reported in the literature (Ref 4-11), increasing diesel fuel sulfur content causes increased engine wear and deposition. These effects were quantified in the 3-53 engine by establishing a low sulfur fuel baseline and a high sulfur fuel baseline while using a constant lubricant (Ref-13). The low sulfur fuel baseline will serve as an example of desired performance level. The overall program objective is to identify fuel and/or lubricant modifications which will result in engine condition similar to the low sulfur baseline, when high sulfur fuel is used continuously. The low sulfur baseline was established using lubricant REO 203 and reference diesel fuel (0.4 wt% S) which is defined by Federal Test Method Standard 791B, Method 341.4. This combination had previously produced excellent results in the 6V53T engine (Ref-3). The high sulfur fuel (HSF) baseline was established using diesel fuel containing 1.0 weight percent sulfur and lubricant REO 203.

TABLE 2. 3-53 ENGINE CHARACTERISTICS

Engine type	Normally Aspirated, Two-cycle compression ignition, direct injection, uniflow scavenging
Weight (dry), kg (lb)	431 (950)
No. of cylinders, arrangement	3 in line
Displacement, liter (cu in.)	2.6 (159)
Bore and stroke, cm(in.)	9.84 x 11.43 (3-7/8 x 4-1/2)
Cylinder block material	cast iron (cast iron liners)
Rated power, kW(Hp)	72.3 (97) at 2800 rpm
Maximum torque, Nm(lb-ft)	278 (205) at 1800 rpm
Compression ratio	21 to 1
Fuel system	Unit injector (N 50 needle valve), primary and secondary engine filters)
Governor	Variable speed with throttle controls
Oil filter	Full-flow single filter
Oil cooling	Integral heat exchanger using 100 percent jacket-coolant flow capacity - 13.2 l (14 qts)
Piston description	
Material/design	Cast iron/trunk type
Ring configuration	1 - Fire ring (rectangular) 3 - Compression rings (rectangular) 2 - Oil rings
Piston cooling	From jet in top of connecting rod

FIGURE - 1

3-53 TEST CELL INSTALLATION

Diesel Engine Model 3-53 Test Facility
(Full Power Fuel Cons. = 6.3 GPH)

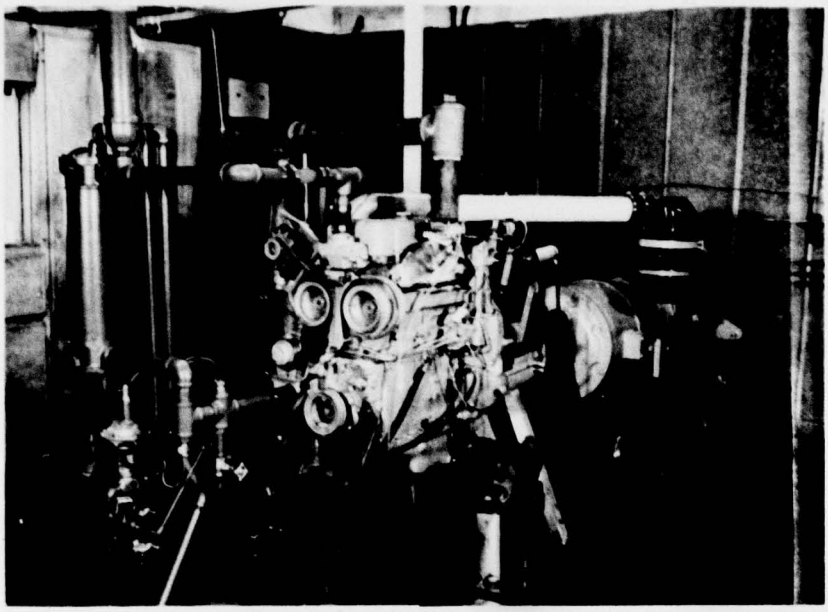

TABLE 3. WHEELED VEHICLE TEST
CYCLE/DAY FOR 15 DAYS

Period	Time, hrs	Load, %	RPM	Coolant Temp, °C(°F)
1	2	100	2800	96 (205)
2	1	0	650	38 (100)
3	2	100	2800	96 (205)
4	1	0	650	38 (100)
5	2	100	2800	96 (205)
6	1	0	650	38 (100)
7	2	100	2800	96 (205)
8	1	0	650	38 (100)
9	2	100	2800	96 (205)
10	10	----------Shutdown----------		
	24			

Complete test is 15 days at 14 hr/day for 210 hours.

Industry was solicated for their help in developing potential solutions to the problem of continuous use of HSF. A letter (Appendix B) was sent to some 29 oil, chemical, and additive companies which requested that they submit fuel additives, lubricant additives, and/or completely formulated lubricants for evaluation. The request was also made during an SAE Open Forum on lubricants in Tulsa, OK during 1977. Materials for evaluation were received from five companies.

D. Test Details

All tests were conducted in 3-53 engine number 3D131703. Between tests new cylinder kits and clean exhaust valves were installed. Before test, the engine was measured for 1) liner bore (top/middle/bottom) at thrust/antithrust and front/back positions, 2) piston diameter, and 3) piston ring gap. After experiencing a blower drive gear failure in Test Number 3, the blower drive gears were replaced after each test. Pre- and post-test full load performance tests were determined using the test fuel.

The engine was operated in accordance with the procedure detailed in Appendix A and summarized in Table 3. The following hourly readings and calculations were made to monitor test operation:

Engine Speed
Engine Load
Torque
Observed Power
Fuel Rate
BMEP
BSFC
Temperatures
- Jacket Coolant-In
- Jacket Coolant-Out
- Oil Sump
- Inlet Air (Blower)
- Exhaust Manifold
- Fuel at Filter

Pressures
- Oil Gallery
- Blower Discharge
- Intake Vacuum
- Exhaust, Common
- Crankcase

Averages of these readings and calculations are presented in the Appendix for each test.

After each test, the engine was disassembled and the following determinations were made:

A. Engine condition ratings in accordance with standard CRC methods (Ref-15, 16) for:
   1. Ring face burning
   2. Ring sticking
   3. Liner scuffing and glazing
   4. Intake port deposits
   5. Ring deposits
   6. Piston deposits
   7. Exhaust valve condition

B. Engine wear measurements for:
   1. Cylinder liner I.D. (top/middle/bottom)
   2. Ring gap
   3. Piston diameter

Oil consumption was calculated and photographs were made of significant engine parts. Used oils were analyzed to determine chemical and physical property changes. The above items are all included in the Appendix for each test.

III. SUMMARIZED RESULTS

This section will present summarized information about the lubricants evaluated, the test fuel used and overall test results. The following section will discuss each test in detail. Table 4 contains a summary of the 3-53 engine tests relevant to this report. The missing test numbers are for tests which were 1) reported earlier, 2) yet to be reported, or 3) not directly applicable. Test Number 1 is the low sulfur fuel (LSF) baseline, which is representative of the desired engine condition at end of test. The average of Test Numbers 4, 12, and 18 is the high sulfur

TABLE 4. SUMMARY OF 3-53 ENGINE TESTS

Test No.	Fuel Sulfur, wt%	Lubricant Code	Lubricant Performance Level	Comments
1	0.4	REO 203	MIL-L-2104C	Low Sulfur fuel baseline
4	1.0	REO 203	MIL-L-2104C	High Sulfur fuel baseline
5	1.0	AL-6576	MIL-L-9000G	Navy Oil
6	1.0	AL-6856	MIL-L-2104C	Army Reference Oil
11	1.0	AL-6942	MIL-L-2104C	Experimental Synthetic Oil
12	1.0	REO 203	MIL-L-2104C	High Sulfur fuel baseline
13	1.0	AL-7135	API SE/CD	Experimental Synthetic Oil
14	1.0	AL-7287	MIL-L-2104C/ MIL-L-46152	Mineral Oil
16	1.0	AL-6950	UK TS1033A	U.K. Reference Oil (ER-5)
18	1.0	REO 203	MIL-L-2104C	High Sulfur fuel baseline

fuel (HSF) baseline. Test Numbers 5, 6, 11, 13, 14, and 16 were evaluations of various lubricants for their effectiveness in combating high sulfur fuel effects. This effectiveness will be determined by comparing the after test engine conditions of a subject lubricant to the LSF and HSF baseline engine conditions.

During the time frame of these tasks, several batches of high sulfur diesel fuel (1.0 weight percent sulfur) were obtained from the same supplier. The fuel contained all straight run material. About 85% of the sulfur content was naturally occurring with the balance obtained through the addition of ditertiary butyl disulfide. All natural occurring sulfur in the test fuel was from the same refinery stream. Table 5 contains the analyses for the reference DF-2 (Test Number 1) and the high sulfur fuels used in this program.

The properties of the lubricants evaluated during this program are presented in Table 6. The low and high sulfur fuel baselines utilized a standard CRC reference engine oil (REO 203) which met the requirements and was qualified under specification MIL-L-2104C. The lubricant from Test Number 6 also met MIL-L-2104C requirements, and is considered a reference oil by the U.S. Army. Test Number 5 was run using a lubricant which met U.S. Navy specification MIL-L-9000G (SHIPS) (Ref-17). Test Numbers 11 and 13 evaluated synthetic based lubricants which were submitted by industry, and were approximately of MIL-L-2104C quality level. The oil evaluated in Test Number 14 was a mineral oil based product submitted by industry and had met the requirements of MIL-L-2104C. Test Number 16 used a mineral based lubricant which is designated a reference oil in the United Kingdom (U.K. ER-5).

Table 7 contains key average operating conditions for these tests. Included are parameters for power, fuel usage, operating temperatures and oil consumption. Table 8 contains a listing of test results including wear measurements for fire ring gap and liner bore change, piston and liner deposition ratings and other pertinent ratings. Table 9 shows a tabulation of the ring sticking performance for each test. Finally, Table 10 contains the used oil analyses which include the

TABLE 5. TEST FUEL PROPERTIES

Property Code	ASTM Method	Test No. 1 Ref DF-2	4,5 AL-6765	6 AL-6933	11,12,13 AL-7178	14,16 AL-7289	18 AL-7766
API°	D 287	33.2	34.6	35.6	34.5	34.7	34.4
Sulfur, wt%	D 2622	ND	1.03	1.05	1.05	1.02	1.03
Sulfur wt%	D 1266	0.42	0.97	1.04	1.01	1.02	1.05
Viscosity, cS at 38°C	D 445	3.20	3.15	3.26	2.68[a]	ND	2.81[a]
Flash Point, °C	D 93	85	ND	54	73	79	82
Cloud Point, °C	D 2500	-5	ND	ND	ND	ND	-15
Pour Point, °C	D 97	-8	ND	ND	ND	ND	-15
Water & Sediment	D 1796	0.0	0.0	0.0	ND	0.0	ND
Carbon Residue, wt%	D 524	0.10	0.19	0.17	0.18	0.19	ND
Copper Corrosion	D 130	1A	1B	1A	1A	1A	ND
Cetane No.	D 613	47	ND	ND	ND	ND	48
Ash, wt%	D 482	0.006	0.001	0.001	ND	ND	ND
H. Htg Value, MJ/kg	D 240	45.47	44.82	44.60	45.00	45.00	ND
BTU/lb		19,500	19,300	19,200	19,400	19,400	
Distillation, °C	D 86						
IBP		210	197	186	197	204	200
10%		242	236	236	225	229	238
50%		271	274	272	262	263	269
90%		317	315	323	310	310	306
EP		365	349	365	352	363	344

ND = Not Determined
a = Kvis @ 40°C

TABLE 6. TEST LUBRICANT PROPERTIES

Property	ASTM Method	Test No. 1,4,12,18 REO 203	5 AL-6576	6 AL-6856	11 AL-6942	13 AL-7135	14 AL-7287	16 AL-6950
Code								
K. Vis, cSt at 38°C	D 445	121.6	132.7	121.0	ND	ND	ND	ND
40°C	D 445	104.6	ND	ND	61.3	67.5	103.3	59.7
99°C	D 445	12.6	13.1	12.0	ND	ND	ND	ND
100°C	D 445	11.8	ND	ND	10.2	10.0	11.4	11.0
Viscosity Index	D 2270	101	100	101	153	143	96	178
TAN	D 664	3.6	1.1	2.3	3.7	2.5	2.2	2.0
TBN	D 2896	5.4	15.1	13.9	10.2	7.9	13.7	4.8
Insolubles, wt%	D 893							
Pentane A		0.05	0.02	0.04	0.09	0.03	ND	ND
Benzene A		0.04	0.01	0.04	0.01	0.01	ND	ND
Pentane B		0.03	0.02	0.03	0.09	0.01	ND	ND
Benzene B		0.02	0.02	0.01	0.02	0.01	ND	ND
API Gravity, °	D 287	27.5	25.9	25.5	21.9	18.4	25.5	29.1
Pour Point, °C	D 97	-21	-15	-17	-41	-34	-21	-30
Flash Point, °C	D 92	241	241	223	227	227	227	226
Carbon Residue	D 524	1.19	1.63	2.10	1.53	1.12	1.82	0.56
Sulfated Ash, wt%	D 874	0.93	1.78	1.64	1.50	1.02	1.63	0.73
Elemental, wt%	Method							
Ba	AA	NIL	NIL	NIL	NIL	NIL	NIL	0.04
Ca	AA (XRF)	0.24	0.49	0.44	0.38	(0.09)	0.40	0.20
Mg	AA	NIL	NIL	NIL	NIL	0.08	NIL	NIL
Zn	AA	0.09	0.05	0.07	0.18	0.13	0.14	0.09
P	XRF	0.09	0.08	0.08	0.12	0.11	0.11	0.05

ND = Not determined.
XRF = X-ray fluorescence

TABLE 7. AVERAGE TEST OPERATING CONDITIONS

Parameter	Test No. 1(LSF)	4,12,18(HSF)	5	6	11	13	14	16
Power (observed), kW	71	72	69.5	72	67	70	70	76
Torque, nm	241	248	237	245	229	237	239	260
BMEP, kPa	586	598	572	593	552	572	579	627
Fuel Rate, kg/hr	19.6	19.2	18.3	20.0	18.0	18.4	18.3	20.0
BSFC, kg/kW-hr	0.276	0.264	0.275	0.278	0.268	0.264	0.262	0.262
Oil Temperature, °C	110	122	121	121	118	117	120	118
Exhaust Temperature, °C	507	523	497	518	493	502	508	547
Total Oil Consumption, kg	15.9	20.4	20.0	18.2	28.2	18.6	27.7	24.5

TABLE 8. TEST RESULTS
Wear, Deposits, and Other Ratings

	Test No.							
	LSF 1	HSF 4, 12, 18	5	6	11	13	14	16
Average Fire Ring Gap Change, μm	51	237	76	330	203	A	102	279
Average Cylinder Liner Bore Change,								
Front-Back and Thrust-Antithrust, μm	8	16	10	20	23	8	15	20
Thrust-Antithrust only, μm	8	23	10	33	25	15	20	25
Average Liner Scuffing, %	4	41	31	33	26	28	22	32
Average Liner Glazing, %	5	9	8	3	2	6	7	13
Deposition								
Piston WTD* Rating								
Cylinder 1	226	393	391	452	446	534	367	336
Cylinder 2	318	374	440	494	370	488	341	461
Cylinder 3	356	345	487	426	363	407	401	531
Average	300	371	439	457	393	476	370	443
Average Port Restriction, %	7	1	2	4	<1	7	2	10
Average Liner Lacquer, %	40	91	92	97	98	94	93	87
Other								
Average Ring Face Burning, % (Fire Ring + 1-3 Compression Rings)	1	32	32	48	31	11	58	42
Used Oil Iron Content, ppm at 210 hrs by XRF	110	117	90	90	60	95	85	149

*WTD = Weighted Total Deposit
A = Not determined, rings stuck

TABLE 9. RING STICKING SUMMARY

Test No.	Ring Sticking (Cylinder-Ring-Condition)
1(LSF)	#2 - F/R - Sluggish #3 - F/R - 15% Cold Stuck
4(HSF)	#3 - F/R - Sluggish
12(HSF)	#2 - F/R - 60% Cold Stuck
18(HSF)	#1 - CR#2 - 5% Cold Stuck
5	#1 - F/R - 10% Cold Stuck
6	#1 - F/R - Sluggish #2 - F/R - 30% Cold Stuck #3 - F/R - Sluggish
11	#1 - F/R - Sluggish #3 - F/R - 80% Cold Stuck
13	#1 - F/R - 90% Hot Stuck; #1 - CR#1 - Sluggish #2 - F/R - 100% Hot Stuck; #3 - CR#1 - Sluggish #3 - F/R - 100% Hot Stuck
14	#2 - F/R - 30% Cold Stuck
16	#1 - F/R - 10% Cold Stuck

TABLE 10. SUMMARY OF USED OIL ANALYSES

Property	Method	LSF Baseline	Avg HSF Baseline	Test 5	Test 6	Test 11	Test 13	Test 14	Test 16
K. Viscosity at 100°C, cSt	D 445								
at 210 hrs		119.8[a]	123.2	158.3[a]	173.5[a]	75.3	71.0	136.6	60.1
Δ from new		-1.8	+18.6	+25.6	+52.5	+14.0	+3.5	+33.3	+0.4
K. Viscosity at 40°C, cSt	D 445								
at 210hrs		12.9[b]	13.4	14.9[b]	15.5[b]	11.8	10.5	13.9	10.0
Δ from new		+0.3	+1.6	+1.8	+3.5	+1.6	+0.5	+2.5	-1.0
TAN at 210 hrs	D 664	3.5	3.6	1.5	3.8	4.7	3.6	4.4	2.8
Δ from new		-0.1	0.0	+0.4	+1.5	+1.0	+1.1	+2.2	+0.8
TBN at 210 hrs	D 2896	4.4	3.6	15.1	12.1	9.2	4.6	12.3	4.2
Δ from new		-1.0	-1.8	0.0	-1.8	-1.0	-3.3	-1.4	-0.6
Flash Point, °C	D 97								
at 210 hrs		238	252	246	221	232	260	241	232
Δ from new		-3	+11	+5	-2	+5	+33	+14	+6
Carbon Residue, wt%	D 524								
at 210 hrs		1.77	2.07	2.95	3.79	2.14	1.82	2.91	1.74
Δ from new		+0.58	+0.88	+1.32	+1.69	+0.61	+0.70	+1.09	+1.18
Sulfated Ash, wt%	D 874								
at 210 hrs		1.09	1.19	2.19	2.03	1.69	1.06	2.13	1.00
Δ from new		+0.16	+0.26	+0.41	+0.39	+0.17	+0.04	+0.50	+0.27
Insolubles, wt% (with coagulent)	D 893								
Pentane, at 210 hrs		0.41	0.40	0.08	0.83	0.03	0.03	0.08	0.05
Δ from new		+0.38	+0.37	+0.06	+0.80	-0.06	+0.02	ND	ND
Benzene, at 210 hrs		0.28	0.12	0.07	0.73	0.02	0.23	0.07	0.10
Δ from new		+0.26	+0.10	+0.05	+0.72	0.0	+0.22	ND	ND
Elemental, ppm	AA(XRF)								
at 210 hrs									
Fe		(110)	82(117)	(90)	(90)	61(60)	87(95)	82(85)	114(149)
Cr		ND	5	<5	8	<5	<5	5	11
Cu		(<50)	9	(<50)	7	5	<1	6	9
Pb		2	43	8	16	11	16	8	11

a = Viscosity determined at 210°F
b = Viscosity determined at 100°F
ND = Not determined

values of selected properties determined at the end of test (210-hours) and the change in property value from new. Having presented the overall summary of test operation and results, each individual test will be discussed in the following section.

IV. DISCUSSION OF RESULTS

In this section, each test will be discussed based on the data presented in Tables 6 through 10. Each test lubricant will be compared to the low and high sulfur fuel baselines to provide an overall assessment of lubricant performance in combating high sulfur fuel effects.

Before discussing the individual tests, the key performance areas of the low and high sulfur fuel baselines will be reviewed. The results of the LSF baseline (Table 8) are representative of the desired engine condition of the test. Measured wear (fire ring gap and cylinder liner bore) were low as were liner scuffing and ring face burning. Piston deposit levels were moderate, and no serious ring sticking problems were observed. Compared to the LSF baseline, the HSF baseline had much more severe ring face burning (32% vs 1%) and cylinder liner scuffing (41% vs 4%). Measured wear was two to four times more severe for the HSF baseline. Piston cleanliness had deteriorated slightly and ring sticking tendency had increased slightly, but still did not approach problem levels. As shown in Table 10, the used oil from the LSF test was still in satisfactory condition while the HSF lubricant had been degraded only slightly more (mainly an increase in flash point and a slight increase in viscosity). The HSF baseline lubricant had increased to SAE 40 viscosity after test, but this was not severe as the new oil itself was on the borderline of being SAE 40. In evaluating the performance of the various test lubricants in combating HSF, our primary objective was to obtain engine condition approaching or equal to the LSF baseline condition when the engine was operated using HSF.

Test Number 5

The lubricant (AL-6576) evaluated in Test Number 5 met the requirements and was qualified under specification MIL-L-9000G (SHIPS) and was viscosity grade SAE 40. It contained a calcium based detergent-dispersant additive system and had a rather high sulfated ash content (1.78 weight percent), and high total base number (15.1).

This test resulted in some improvement in overall engine condition as compared to the HSF baseline. As shown in Table 8, fire ring gap wear was significantly reduced while liner bore change and liner scuffing were slightly reduced with AL-6576. No improvement in ring face burning was observed and a detriment in piston cleanliness resulted. No significant ring sticking occurred during this test (Table 9). Used oil analyses (Table 10) revealed that the condition of AL-6576 was not significantly degraded. While Test Number 5 showed some marked improvement over the HSF baseline, its overall performance did not approach the excellent performance observed for the LSF baseline, except for fire ring end-gap wear which were comparable.

Test Number 6

The lubricant (AL-6856) evaluated in Test Number 6 met the requirements and was qualified under specification MIL-L-2104C, SAE grade 30, and is considered by the Army to be a MIL-L-2104C reference lubricant. This oil contained a calcium based detergent-dispersant additive system with a sulfated ash of 1.64 weight percent and a total base number of 13.9.

As shown in Table 8, use of this lubricant resulted in no significant improvement in engine condition as compared to the HSF baseline. In fact, fire ring gap wear was much more severe as was ring face burning. Piston deposit levels were consistently higher than the HSF baseline. Only the average cylinder liner scuffing showed a slight improvment in Test Number 6. Ring sticking (Table 9) was similar to that observed in the HSF baseline tests. The used oil analyses (Table 10) revealed that AL-6856 thickened from an SAE 30 to an SAE 40 viscosity grade during the

test. This increase was probably caused primarily by soot accumulation as the carbon residue and insolubles values increased significantly during the test. Overall, the use of AL-6856 did not reduce or counteract the detrimental effects of using HSF.

Test Number 11

The lubricant (AL-6942) evaluated in Test Number 11 was described by its manufacturer as "an experimental synthetic non VI-improved SAE 10W-30 lubricant." Discussions with the manufacturer revealed that AL-6942 was a blend of synthesized hydrocarbon and ester material. AL-6942 was formulated to meet the requirements of MIL-L-2104C and API service classification SE. This oil contained a calcium based detergent-dispersant additive system, with a sulfated ash of 1.50 weight percent and a total base number of 10.2.

Compared to the HSF baseline, Test Number 11 had very similar results as shown in Table 8. The average cylinder liner scuffing was slightly reduced for Test 10. However, the key areas of ring face burning and measured ring and liner wear were not significantly improved. Piston cleanliness (Table 8) and ring sticking (Table 9) were comparable to the HSF baseline. The used oil properties (Table 10) indicated that the lubricant was still in satisfactory condition at 210 hours as there were no substantial changes in oil properties. Overall, the use of AL-6942 did not result in the desired engine condition when high sulfur fuel was used.

Test Number 13

The lubricant (AL-7135) evaluated in Test Number 13 was described by its manufacturer as a "polyol ester based lubricant which contains no viscosity index improver." AL-7135 was formulated to meet the requirements of API service classifications SE and CD. The oil contained a mixed calcium and magnesium based detergent-dispersant additive system which resulted in a sulfated ash of 1.02 weight percent and a total base number of 7.9.

As shown in Table 8, evaluation of AL-7135 resulted in very good performance in some areas and very bad performance in other areas. Relative to the HSF baseline, Test 13 showed good improvement in overall average cylinder liner bore wear, and a very significant reduction in ring face burning, while the average cylinder liner scuffing was moderately reduced. Unfortunately, the use of AL-7135 resulted in severely hot-stuck fire rings in all three cylinders (Table 9). Piston deposits were rather heavy which probably was a consequence of the stuck fire rings. The used oil analyses (Table 10) revealed a large increase in flash point of the lubricant (+33°C) and a significant reduction in total base number. Other lubricant properties were not significantly degraded. Overall, the use of AL-7135 offered promise for controlling some of the HSF effects such as ring face distress; however, the hot stuck fire rings negate the possible use of this lubricant as a solution to the HSF problem.

Test Number 14

The lubricant (AL-7287) evaluated in Test Number 14 was described by its manufacturer as a "mineral base stock oil that meets the performance requirements of MIL-L-46152 and MIL-L-2104C." The lubricant was viscosity grade SAE 30 and had a calcium based detergent-dispersant additive system. The sulfated ash was 1.63 weight percent and the total base number was 11.4.

Compared to the HSF baseline, the use of AL-7287 resulted in mixed performance (Table 8). Ring face burning was much more severe with AL-7287, while the average cylinder liner scuffing was moderately reduced. The average fire ring gap wear was significantly reduced in Test 14, while the cylinder liner bore wear, piston deposit ratings, and ring sticking (Table 9) were very similar to the HSF baseline. The used oil analyses (Table 10) show that the viscosity had increased to an SAE 40 grade and that the flash point had increased moderately (+14°C). The carbon residue had increased (+1.09 weight percent) indicating a buildup of combustion byproducts, while the insolubles did not reach significant levels.

Overall, AL-7287 did not approach the desired level of performance observed in the LSF baseline.

Test Number 16

The lubricant (AL-6950) evaluated in Test Number 16 was a United Kingdom reference oil (ER-5). AL-6950 was evaluated because it had given acceptable performance in a United Kingdom four-cycle diesel engine test which used high sulfur fuel (1.0 weight percent). This lubricant contained conventional petroleum basestocks and met the viscosity requirements of SAE 10W-30. AL-6950 had a calcium based detergent-dispersant additive system with a sulfated ash of 0.73 weight percent and a total base number of 4.8.

Compared to the HSF baseline, the use of AL-6950 did not result in any significant improvement in engine condition (Table 8). Measured wear (fire ring gap and cylinder liner bore), ring face burning and piston deposits were all equal to or worse than the HSF baseline. No serious ring sticking was encountered with AL-6950 and the used oil analyses (Table 11) showed only a moderate increase in flash point (+7°C). The used oil iron content was slightly higher than the HSF baseline. Overall, the use of AL-6950 did not result in the desired level of performance observed in the LSF baseline.

V. CONCLUSIONS/RECOMMENDATIONS

A qualitative summary assessment of the performance of the lubricants tested in this program is presented in Table 11. The following conclusions are made based on the work covered in this report:

- To date, none of the lubricants tested would allow the continous use of HSF without a penalty in engine condition as compared to LSF utilizaton.

- One lubricant (AL-6576) which met the requirements of specification MIL-L-9000G (SHIPS) yielded significant improvement in measured wear, but no improvement in ring face condition when high sulfur fuel was used.

TABLE 11. SUMMARY OF LUBRICANT PERFORMANCE COMPARED TO HSF BASELINE

Performance Area	Test No. 5 AL-6576	6 AL-6856	11 AL-6942	13 AL-7135	14 AL-7287	16 AL-6950
Fire Ring Wear	++	--	o	A	+	--
Ring Face Burning	o	--	o	++	--	--
Cylinder Liner Wear	+	--	--	++	o	--
Cylinder Liner Scuffing	+	+	+	+	+	+
Piston Cleanliness	--	--	o	--	o	--
Ring Sticking	o	o	o	--	o	o

++ = Improvement approaching LSF baseline
+ = Improvement
-- = Worse than HSF baseline
o = Approximately the same
A = Not determined, rings stuck

- Lubricant AL-7135 gave improved performance in measured wear and ring face condition compared to the HSF baseline; however, severe fire ring sticking occurred with this oil which precludes further evaluations of it.

- The other lubricants tested with HSF resulted in slight or no overall improvement in engine condition. (Some even resulted in worse performance than the HSF baseline).

The following recommendations for future effort are offered:

- Additional lubricants which are specially formulated to counteract the deleterious effects of using HSF should be developed and tested.

- Additional lubricants from within the military supply system should be tested with HSF (e.g. MIL-L-21260B Preservative Oil, and MIL-L-46167 Arctic Engine Oil) to further define the current status of the problem.

- Fuel additives for combating HSF effects need to be identified and tested.

- Additional effort needs to be undertaken to aid in the base understanding of the fuel combustion and engine degradation mechanisms involved with HSF.

- Future Army engine oil specifications should include both two and four cycle diesel engine test requirements using HSF.

VI. ACKNOWLEDGEMENTS

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Ms. R.J. Shew	Typing

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APPENDIX A

Wheeled-Vehicle Test Procedure

APPENDIX

WHEELED-VEHICLE TEST PROCEDURE
DD 3-53 ENGINE

Test No.: _____ Engine Serial No.: _____ Test Cell No.: __

Test Lubricant: _____ Test Fuel: _____

Instructions

1. Pre-Test Preparations.

1.1 Filter Elements. Install new element in oil filter and change oil in air filter bath (using test oil).

1.2 Sump Oil Charge. Charge engine sump to full mark on dip-stick with test oil (AL- -L). Close filler cap and motor engine for one minute at low speed (about 500 RPM) to fill oil cooler, filter, and internal oil passages. Recheck level and add to full mark again (should be about 25 lbs).

1.3 Priming Fuel System. After changing over to Ref DF-2 fuel and flushing fuel lines, remove the Allen plug from top of primary fuel filter and fill the filter with fuel, then re-install plug.

1.4 Break-In Procedure. Set jacket coolant-out temp. controller at 205°F. Start engine and idle at 650 RPM for five minutes, then warm up at about 1000 to 1200 RPM for ten minutes. If no engine malfunctions or leakages occur, conduct the following break-in and record complete log sheet readings at end of each setting. Calculate: BHP, Torque, BSFC, BMEP.

Time Minutes	Speed RPM	Load lb	Jacket-Out Temperature °F
30	1800	25	205
30	2200	55	205
30	2500	80	205
30	2800	80	205

1.5 Full Load Performance Test. Following the break-in run, conduct a full load performance test run at the following conditions. Allow conditions to stabilize at each speed, then record complete log sheet readings at end of each setting. Calculate BHP, Torque, BSFC, BMEP.

Speed, RPM	Jacket-Out, °F
1600	205
1800	205
2000	205
2200	205
2400	205
2600	205
2800	205

1.6 Valve Clearance Check. Upon completing the full load performance test, stop engine and immediately check the hot clearance of the exhaust valves. Adjust clearances to .023-.025 in, also check injector height per gauge.

1.7 Oil and Fuel Change-Over. Upon completing valve clearance check, drain oil sump and filter. Discard drain and oil filter element. Weigh and record (on oil consumption log) a new oil filter element. Install new oil filter and then charge system with full charge of test oil (AL- -L) as in item 1.2. Record weight of total charge. Change over to test fuel (AL- -F) and flush fuel lines. Replace both fuel filter elements and prime as in item 1.3. Weigh oil blowby can and record (oil consumption log).

1.8 Full Load Performance Test. Following fuel change-over, run full load performance test as in item 1.5.

Check and Adjust Oil Level Before Starting Test.

2. Test.

2.1 Warm-Up. At the start of each day--idle for five minutes, then start test cycle at 2800 RPM.

2.2 Test Conditions. After warm-up, the following test cycle conditions are followed:

Test Cycle for 15 Days

Period	Time, Hrs	Load, %	RPM	Coolant Temp., °F
1	2	100	2800±20	205±2
2	1	0	650±25	100±2
3	2	100	2800	200
4	1	0	650	100
5	2	100	2800	205
6	1	0	650	100
7	2	100	2800	205
8	1	0	650	100
9	2	100	2800	205
10	10	--------Shut Down---------		

Operate at test conditions 14 hours/day for a total of 210 hours. Complete log sheet readings at end of each period. Calculate: BHP, Torque, BSFC, BMEP.

2.3 Daily Cool-Down. After the last test hour each day, reduce the speed to idle (600-650 RPM) for five minutes, (without resetting coolant controller) then stop engine.

2.4 Used Oil Samples. Flush oil filter tap, and withdraw a used oil sample during daily 5-minute cool-down (item 2.3) according to the Oil Consumption Log schedule and record sample weight.

Identify each sample as to test hours, test No. and oil code (AL- -L). Take: 2 oz. sample each day except at 70 and 140 hours take 12 oz. sample. At end of test take 16 oz. sample. Take daily oil samples to Chem Lab for elemental analyses by XRF.

2.5 Oil Additions. New test oil additions, if required, are to be made at the end of each day after shutdown. Allow five minutes for oil to drain back to sump. Add weighed new oil to restore sump level to full by dipstick. Record weight of add-on oil consumption log.

2.6 Final Oil Drain. Upon completion of post test power curves and while engine is warm, drain the sump, saving one gallon of used oil in clean can. Tag can, showing test No., oil code, date, and test hour. Also remove oil filter element, weigh and record.

2.7 Notes and Limits.

(1) Coolant is 50% glycol/50% water.

(2) Coolant Out temperature must be reduced to 100°F within 15 minutes after idle starts.

(3) Limits/Tolerances: Coolant Out Temperature: ±2°F of designated temperature.

Oil Sump Temperature: 265°F max.

Fuel @ Filter Temperature: 90±5°F (105°F max.=shutdown).

(4) No Oil Change during test.

3. After Test.

3.1 Full Load Performance Test. At end of test, run full load performance test as in item 1.5.

3.2 Valve Clearance Check. Upon completing end of test power curve, item 3.1, check hot valve clearances and record.

3.3 Wear and Deposits. Upon disassembly of engine, check wear measurements and deposit ratings (on sheets provided).

3.4 Record amount of fuel used for test.

3.5 Calculations (for AFLRL Cell No. 2: BHP (obs.) = Load x RPM/3000

Torque (lb-ft) = Load x 1.75

BSFC (lb/Bhp-hr) = lbs Fuel per hr/BHP (obs.)

BMEP (psi) = Torque x 0.474

4. Cell Notebook.

4.1 Keep cell notebook updated (like a diary) at all times. Record what is being done (changes or repairs) to the cell engine, instruments, etc. Record anything unusual and all modifications.

OIL CONSUMPTION LOG

Oil Addition Record

Test Hours	Op. Init.	Weight Oil & Can Before Add	Weight Oil & Can After Add	Weight of Oil Added
14				
28				
42				
56				
70				
84				
98				
112				
126				
140				
154				
168				
182				
196				
210				

Total Additions _____

Oil Samples

Test Hours	Op. Init.	Weight of Sample & Bottle	Weight of Sample
14			
28			
42			
56			
*70			
84			
98			
112			
126			
*140			
154			
168			
182			
196			
*210			

Total Samples _____

Oil Code _____
Test No. _____

Wt Initial Oil Fill _____

Wt Total Oil Adds _____

Wt Fill Plus Adds _____

Wt Total Oil Samples _____

Wt Final Oil Drain _____

Wt Used Filter _____

Wt New Filter _____

Wt Oil in Filter _____

Total Oil Drains _____

Total Oil Cons. _____

All Weights are in Pounds.
* - Large Samples - 12 oz.; all others are 2 oz.

APPENDIX B

Letter to Oil, Chemical, and Additive Companies

DEPARTMENT OF THE ARMY Bowen/mb/43576
US ARMY MOBILITY EQUIPMENT RESEARCH & DEVELOPMENT COMMAND
FORT BELVOIR, VIRGINIA 22060

DRDME-GL

14 July 1977

SEE DISTRIBUTION LIST

Gentlemen:

In our letter of 2 March 1977 concerning multigraded engine oil, we indicated the Army was experiencing a problem with high-sulfur diesel fuels. The purpose of this letter is to solicit your assistance in developing a solution to this problem. The difficulty occurs during the continuous operation of Army diesel powered equipment on high-sulfur fuel (>0.5%S). Diesel fuels purchased OCONUS by the Army are consistently running in excess of 0.5% sulfur and have contained as much as 1.2% sulfur. The problem is more critical in two-cycle diesel engines with engine failures reported from areas where high-sulfur fuels have been used. The Army fleet contains a significant number of two-cycle diesel powered engines as shown by Table 1. Laboratory investigations have confirmed the effect of high-sulfur diesel fuel on Army two-cycle diesel equipment (SAE paper No. 760717). Specific problem areas documented by the laboratory investigations included: catastrophic piston/ring/exhaust valve failure and relatively high deposit and wear levels.

Fuel and/or lubricant modifications hold promise for solving the Army's problem of operating continuously on high-sulfur fuel. The Army envisions three possible approaches, which include:

Approach No. 1: a fuel additive added at the refinery which would counteract the deleterious effects of fuel sulfur combustion products. This additive would be requested for use only in areas where high sulfur diesel fuel is being used continuously.

Approach No. 2: a lubricant additive package added by the lubricant blender to current MIL-L-2104C qualified products. This package must be completely compatible with all qualified MIL-L-2104C products and must allow continuous operation on high-sulfur fuels while still maintaining excellent overall MIL-L-2104C performance. This lubricant would be used only where continuous operation on high-sulfur fuels is encountered.

Approach No. 3: a new generation of diesel lubricants containing a specially balanced and formulated additive package to give excellent performance in both two and four-cycle diesel engines operated on high-sulfur fuel. In addition to meeting future anticipated MIL-L-2104C requirements as defined in our letter of 2 March 1977, this new generation of lubricants would directly replace the current MIL-L-2104C lubricant for use in *all* nonarctic operated Army combat/tactical equipment.

If Approach No. 3 is taken, the Army would like to *ultimately* see the new generation lubricant include multigrade technology as discussed at the SAE open forum in Tulsa, Oklahoma (June, 1977). It is understandable and acceptable to the Army if lubricant/additive suppliers determine that multigrade technology and high-sulfur fuel/lubricant technology each must be developed separately and in a stepwise manner. However, the *ultimate lubricant* desired must have both multigrade characteristics and be able to counteract the deleterious effects of high-sulfur fuel.

Currently the Army is developing baseline information on fuel sulfur effects in the DDAD 3-53 engine which is the power plant in the Army's 1-1/4 ton M561 (Gamma Goat). The engine has been installed at the U.S. Army Fuels and Lubricants Research Laboratory in San Antonio, Texas. Once baseline determinations are completed, the exact performance target can be set. Presently, we are defining acceptable performance with high-sulfur fuel (1.0%S) as wear and deposition not greater than that obtained from a reference lubricant (REO 203) and low-sulfur fuel (0.4%S) in the 3-53 engine. The test procedure being followed is the Army's 210-hour wheeled-vehicle test cycles as defined in SAE paper No. 760717. If approaches 2 or 3 are followed, the Caterpillar OL-1 test will be used in addition to MIL-L-2104C requirements to determine four-cycle compatibility of the new lubricant. If approach No. 1 is followed, the fuel additive supplier must submit data showing both two-cycle and four-cycle diesel engine compatibility for his proposed fuel additive.

Suppliers who believe they could furnish a product meeting the requirements described herein should forward a 50-gallon drum of the finished lubricant or sufficient fuel additive to treat 2000 gallons of fuel to:

U.S. Army Fuels and Lubricants Research Laboratory
Southwest Research Institute
Attn: Mr. E. A. Frame
8500 Culebra Road
San Antonio, Texas 78284

An additional 5-gallon finished lubricant sample or 1-gallon fuel additive sample should be sent to:

Commander
U.S. Army Mobility Equipment Research & Development Command
Attn: DRDME-GL, Mr. T. C. Bowen
Ft. Belvoir, Virginia 22060

Priority will be given to lubricant samples submitted with MIL-L-2104C engine test data and the Caterpillar OL-1 test results and to fuel additives with engine test data supporting the recommendation. The Army will conduct the previously mentioned 3-53 two-cycle diesel engine tests.

In closing, suppliers are again reminded that (1) the Army diesel-powered fleet has a special lubrication requirement; i.e., operation over any kind of terrain, under all kinds of climatic conditions coupled with the combined requirements of a diverse inventory of specialized ground-powered equipment and extremely severe operating cycles, (2) test results will be provided to suppliers; however, test data generated by the Army does not constitute an official endorsement of any lubricant or fuel additive.

Sincerely yours,

Maurice E LePera

MAURICE E. LEPERA
Chief, Fuels & Lubricants Division

1 Incl
as

CF: AFLRL

Table 1 Army Tactical Vehicles Powered by GMC Detroit Diesel Two-Cycle Engines

Designation	Description	Engine Model
M106A1	Mortar, Self-Propelled, 107 MM	6V53
M107	Gun, Self-Propelled, 175 MM	8V71T
M109	Howitzer, Self-Propelled, 105 MM	8V71T
M109	Howitzer, Medium, 155 MM	8V71T
M110	Howitzer, Self-Propelled	8V71T
M113A1	Carrier, Personnel	6V53
M125A1	Mortar, Self-Propelled, Full-Tracked	6V53
M132A1	Flame Thrower, Self-Propelled	6V53
M548	Carrier, Cargo, Tracked, 6-Ton	6V53
M551	Armored Reconnaissance/Airborne Assault Vehicle (Sheridan)	6V53T
M561	Gamma Goat	3-53
M577A1	Carrier, Command Post, Light Tracked	6V53
M578	Recovery Vehicle	8V71T
M116	Cargo Carrier, Amphibious, Tracked,	3-53
HET70	Heavy Equipment Transporter	12V71T
XM 667	Carrier, GM, Equipment, SP	*
XM 727	Carrier, GM, Equipment, SP	*
XM 730	Carrier, GM, Equipment, SP	*
XM 741	Chassis, Gun, AA Artillery, 20 MM, SP	*
XM 806E1	Recovery Vehicle, FT Armored	*
--	Truck, Dump, 20-Ton, Diesel Electric Driven	6V71

*Vehicles are powered by either 6V53, 6V53T, or 8V71T (TB-750-652).
Note: All new and rebuilt series 53 engines use trunk-type pistons. Only the recently procurred and currently rebuilt series 71 engines use the cross-head type piston.

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Gulf Oil Chemicals Co. (M. Campen)
Imperial Oil Enterprises (G. Holmes)
Lubrizol Corp. (J. Creedon)
Mobil Research & Development Corp. (V. Lowther
Paramins Laboratories (A. Schetelich)
Petrolite Corp., Tretolite Div. (Grenzer)
Phillips Petroleum Co. (K. Yochum)
Rohn & Haas (R. Schum)
R. T. Vanderbilt Company, Inc. (W. Suyden)
Shell Research & Development Corp. (D. Olson)
Standard Oil of Ohio (R. L. Pontious)
Stauffer Chemical Co. (G. Berens)
Sun Oil Co. (W. Crouse)
Texaco Inc. (R. Paggi)
Union Oil Co. (F. Liggett)
W. R. Grace, Hatco Chemicals (J. Newcomb)

APPENDIX C

3-53 TEST #5

FUEL: 1% S, DF-2

LUBE: MIL-L-9000G, AL-6576

START: 30 MARCH 1977

END: 19 APRIL 1977

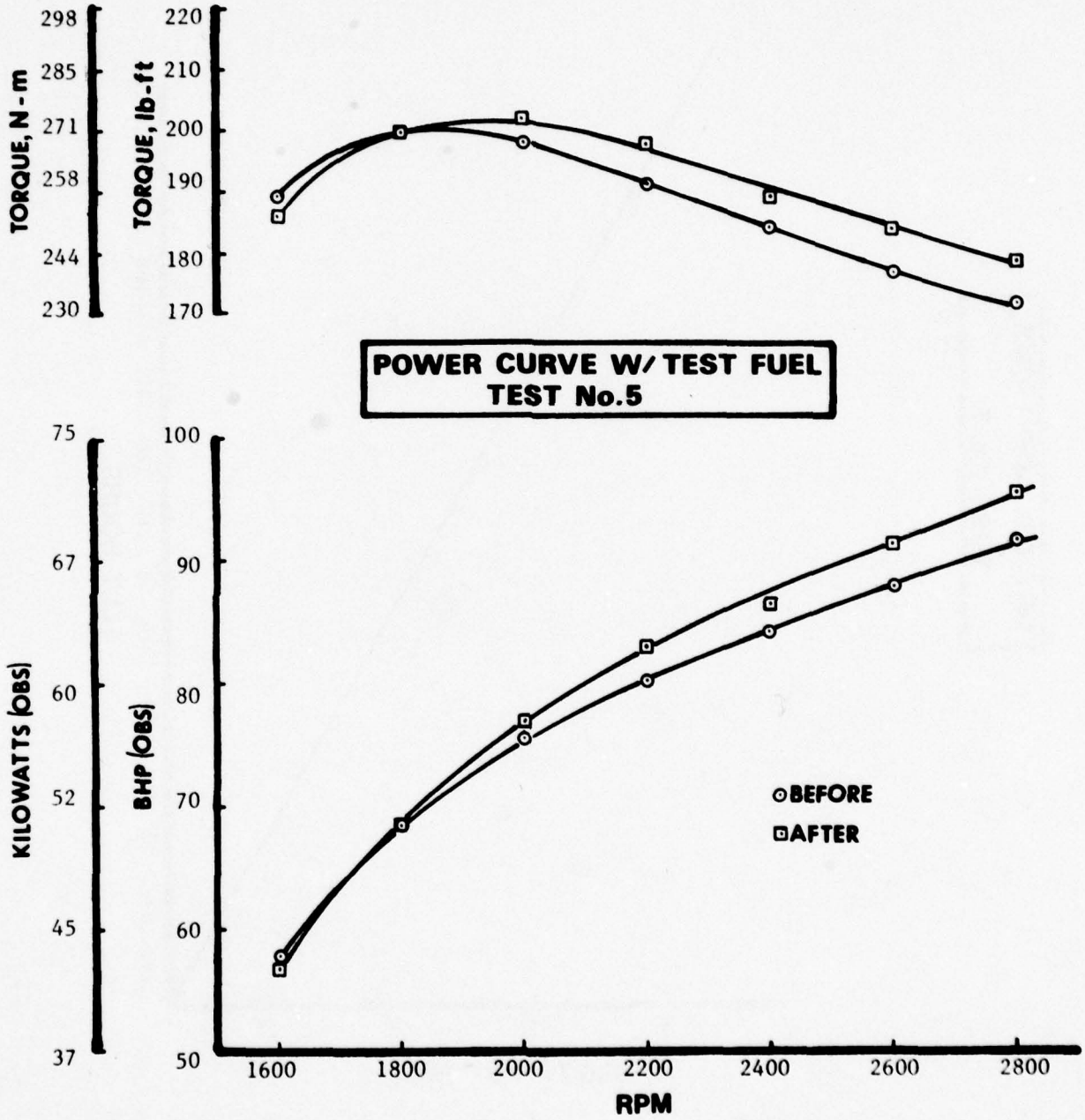
ENGINE OPERATING DATA (AVG)
TEST #5

	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2797	2808	2802	645
Load, lbs	98	102	99	
Torque, lb-ft	171.5	178.5	174.8	
BHp obs	91.5	95.2	93.2	
Fuel Rate, lb/hr	39.5	43.7	40.4	
BMEP, psi	81.3	84.6	82.9	
BSFC lb/BHp-hr	.429	.466	.452	
Temperatures, °F				
Jacket Coolant-In	194	199	196.5	94
Jacket Coolant-Out	204	205	204.3	100
Oil Sump	248	253	250.5	
Inlet Air (Blower)	70	104	89.5	
Exhaust Manifold	810	950	926	
Fuel @ Return	139	150	144.7	
Pressures				
Oil Gallery, psig	42.0	45.6	43.5	29
Blower Discharge, Airbox, psig	7.2	8.6	8.1	
Intake Vacuum, in. H_2O	6.4	7.4	7.0	
Exhaust, Common, in. Hg	2.7	3.3	3.0	

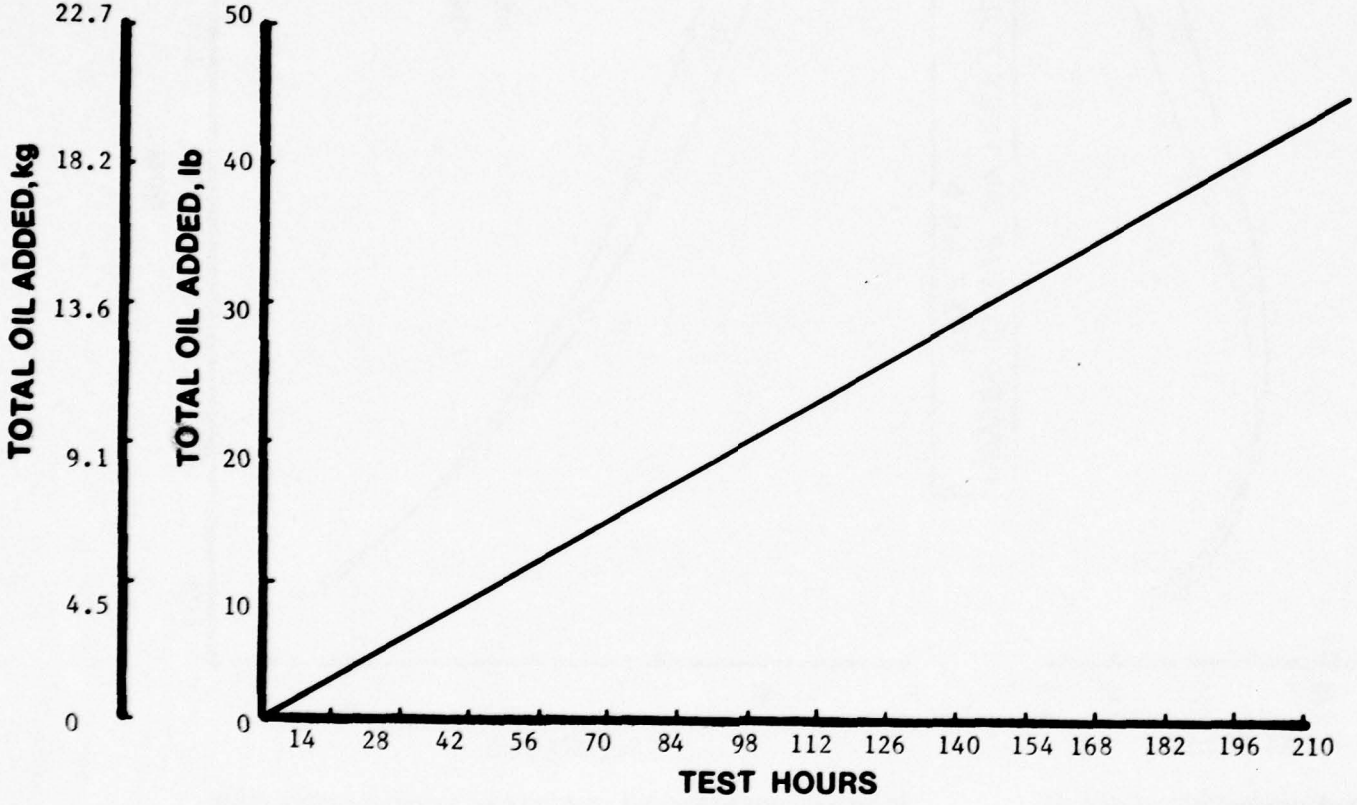
LUBRICANT ANALYSES (AL-6576)
TEST #5

Property	ASTM Method	New Oil	70 Hrs	140 Hrs	210 Hrs
K. Vis, cS, 38°C (100°F)	D445	132.7	145.3	155.7	158.3
K. Vis, cS, 99°C (210°F)	D445	13.1	14.1	14.7	14.9
VI	D2270	100	101	101	102
TAN	D664	1.1	2.0	1.9	1.5
TBN	D2896	15.1	13.7	15.4	15.1
Insolubles, wt%	D893				
Pentane A		0.02	---	---	0.04
Benzene A		0.01	---	---	0.03
Pentane B		0.02	---	---	0.08
Benzene B		0.02	---	---	0.07
API Gravity, °	D287	25.9	---	---	24.6
Pour Point, °C	D97	-15	---	---	---
Flash Point, °C	D92	241	---	---	246
Carbon Residue, wt%	D524	1.63	2.40	2.82	2.95
Sulfated Ash, wt%	D874	1.78	1.98	2.13	2.19
Elemental	Method				
Ba, ppm	XRF	< 300	---	---	---
Mg, ppm	AA	4	---	---	---
Ca, wt%	XRF/AA	0.55/0.49	---	---	---
Zn, wt%	XRF/AA	0.05/0.05	---	---	---
Na, ppm	AA	---	113	---	132
Cu, ppm	XRF	---	< 30	---	< 30
Cr, ppm	AA	---	---	---	< 5
Pb, ppm	AA	---	---	---	8
Sn, ppm	AA	---	---	---	< 50
Fe, ppm	XRF	---	72	90	90
Cl, ppm	XRF	540	---	---	---

--- = Not Determined.
AA = Atomic Absorption.
XRF = X-Ray Fluorescence.


TORQUE, N-m
298
285
271
258
244
230
TORQUE, lb-ft
220
210
200
190
180
170
POWER CURVE W/ TEST FUEL
TEST No.5
KILOWATTS (OBS)
75
67
60
52
45
37
BHP (OBS)
100
90
80
70
60
50
1600
1800
2000
2200
2400
2600
2800
RPM
BEFORE
AFTER

NET OIL ADDITIONS
TEST No. 5



RING FACE CONDITION: % BURNING
TEST #5

	Cylinder Number		
	1	2	3
First Ring	3	90	15
Second Ring	1	3	15
Third Ring	N	70	80
Fourth Ring	N	30	80
Average of all	32%		
Average w/o Cyl-1	48%		

N = Normal

RING STICKING
TEST #5

Ring No.	Piston Number		
	1	2	3
1	10% Cold Stuck	F	F
2	F	F	F
3	F	F	F
4	F	F	F

F = Free

CYLINDER LINERS
TEST #5

Cylinder Liner Scuffing
Percent of Compression Ring
Travel Area

Cylinder Number	Percent Port Restriction	Percent Scuffed		% Total Area Scuffed	% Glazed	% Lacquer
		Thrust	Anti-Thrust			
1	2	5	50	28	15	85
2	2	5	45	25	5	92
3	3	5	75	40	5	95
Average	2	5	57	31	8	92

PISTON O.D. (IN)
TEST #5

Cylinder	1	2	3
Before	3.8710	3.8710	3.8710
After	3.8710	3.8710	3.8710
Δ	0	0	0

PISTON SURFACE CONDITION
TEST #5

	Piston Number		
	1	2	3
Top Land	N	N	N
Skirt	N	Lt. Scratch	Lt. Scratch
Piston Pin	N	N	N

PISTON GROOVE INSIDE DIAMETER - % RING SUPPORTING CARBON
TEST #5

Piston Ring	Quadrant	Piston Number 1	2	3
1	1	80	85	90
	2	0	0	0
	3	0	0	15
	4	0	0	5
2	1	0	40	5
	2	15	0	100
	3	0	5	95
	4	0	100	0

Quadrants:

1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #5

Area	Cylinder No. 1	2	3
Head	All 100%-AHC to Soot		
Face	All 100%-9 to Clean		
Tulip	All 100%-9		
Stem	All 50%-9 to Clean		

EXHAUST VALVE SURFACE CONDITIONS
TEST #5

	Cylinder No. 1	2	3
Freeness in Guide	F	F	F
Head		All Normal	
Face		Signs of Leaking	N
Seat	Leaking	OK	OK
Stem		All Normal	
Tip		All Normal	

RING DEPOSITS
TEST #5

Cylinder Number		1		2		3	
	Ring	CARB	LACQ	CARB	LACQ	CARB	LACQ
Top	1	90-1/2 AHC	10-8	10-1/2 AHC	90-9	10-1/2 AHC	95-9
	2	0	95-9	0	50-9	10-1/2 AHC	90-9
	3	0	10-8	0	15-8, 35-7 5-9	0	100-9
	4	0	90-6 100-3	0	95-8 100-5	0	100-2
ID	1	100-1/2 AHC	0	15-AHC	0	100-1/2 AHC	0
	2	100-AHC	0	85-1/2 AHC 100-AHC	0	15-AHC	0
	3	100-1/2 AHC	0	25-AHC	0	85-1/2 AHC 10-AHC	0
	4	100-1/2 AHC	0	75-1/2 AHC 0	100-9	90-1/2 AHC 0	100-9
Bottom	1	0	20-7	0	5-9	0	100-3
	2	0	5-8 10-5	0	5-8, 10-7 100-3	0	5-9, 25-7
	3	0	40-3	0	50-3	0	80-3 100-4
	4	0	100-2	0	50-2 100-2	0	100-2

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-6576

RATER E.R. Lyons DATE 4-25-77
LABORATORY TEST NUMBER 3-53-5
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1% S, DF-2

PISTON NO. 1

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	391

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	GROOVES NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	GROOVES NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	GROOVES NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	GROOVES NO. 4 DEMERIT	LANDS NO. 1 AREA-%	LANDS NO. 1 DEMERIT	LANDS NO. 2 AREA-%	LANDS NO. 2 DEMERIT	LANDS NO. 3 AREA-%	LANDS NO. 3 DEMERIT	LANDS NO. 4 AREA-%	LANDS NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00	15	15.00	50	50.00					60	60.00	70	70.00						
	MHC	0.75	25	18.75	30	22.50	25	18.75					10	7.50	20	15.00				
	MC	0.50	60	30.00	20	10.00	5	2.50	15	7.50			5	2.50	10	5.00				
	LC	0.25									40	10.00	5	1.25			10	2.50		
	VLC	0.15															40	6.00		
	CARBON RATING		63.75		82.50		21.25		7.50		70.00		81.25		20.00		8.50			
LACQUER	BL	0.100					70	7.00	85	8.50			10	1.00	70	7.00			100	10.00
	DBrL	0.075															20	1.50		
	AL	0.050															30	1.50		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING						7.00		8.50				1.00		7.00		3.00		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			63.75		82.50		28.25		16.00		70.00		82.25		27.00		11.50		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-6576

RATER E.R. Lyons DATE 4-25-77
LABORATORY TEST NUMBER 3-53-5
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1% S, DF-2

PISTON NO. 2

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	440

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	GROOVES NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	GROOVES NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	GROOVES NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	GROOVES NO. 4 DEMERIT	LANDS NO. 1 AREA-%	LANDS NO. 1 DEMERIT	LANDS NO. 2 AREA-%	LANDS NO. 2 DEMERIT	LANDS NO. 3 AREA-%	LANDS NO. 3 DEMERIT	LANDS NO. 4 AREA-%	LANDS NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00	15	15.00	50	50.00	5	5.00			20	20.00	65	65.00	80	80.00				
CARBON	MHC	0.75	45	33.75	50	37.50	15	11.25					15	11.25						
CARBON	MC	0.50	30	15.00			40	20.00	45	22.50										
CARBON	LC	0.25									35	8.75	10	2.50	20	5.00				
CARBON	VLC	0.15									40	6.00					20	3.00		
	CARBON RATING		63.75		87.50		36.25		22.50		34.75		78.75		85.00		3.00			
LACQUER	BL	0.100					40	4.00	55	5.50	5	.50	10	1.00			65	6.50	100	10.00
LACQUER	DBrL	0.075																		
LACQUER	AL	0.050															10	.50		
LACQUER	LAL	0.025															5	.125		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001																		
	LACQUER RATING						4.00		5.50		.50		1.00				7.125		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			63.75		87.50		40.25		28.00		35.25		79.75		85.00		10.125		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-6576

RATER E.R. Lyons DATE 4-25-77
LABORATORY TEST NUMBER 3-53-5
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1% S, DF-2

PISTON NO. 3

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	487

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1		GROOVES NO. 2		GROOVES NO. 3		GROOVES NO. 4		LANDS NO. 1		LANDS NO. 2		LANDS NO. 3		LANDS NO. 4		UNDER-CROWN	
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00	50	50.00	50	50.00	15	15.00			35	35.00	75	75.00	50	50.00				
	MHC	0.75	50	37.50	50	37.50	5	3.75			5	3.75	25	18.75						
	MC	0.50					25	12.50			10	5.00			40	20.00				
	LC	0.25					45	11.25	75	18.75	50	12.50			10	2.50	50	12.50		
	VLC	0.15					10	1.50									10	1.50		
	CARBON RATING		87.50		87.50		44.00		18.75		56.25		93.75		72.50		14.00			
LACQUER	BL	0.100							25	2.50									10	10.00
	DBrL	0.075																		
	AL	0.050															5	.125		
	LAL	0.025															10	.25		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING								2.50								.375		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			87.50		87.50		44.00		21.25		56.25		93.75		72.50		14.375		10.00	

*WEIGHTED TOTAL DEPOSITS

09

CYLINDER LINER I.D. (IN)
TEST #5

Cylinder No.		Front/Back Parallel to Crank Top	Middle	Bottom	Thrust/Antithrust Perpendicular to Crank Top	Middle	Bottom
1.	After	3.8763	3.8764	3.8768	3.8764	3.8766	3.8770
	Before	3.8760	3.8763	3.8766	3.8761	3.8763	3.8766
	Δ	.0003	.0001	.0002	.0003	.0003	.0004
2.	After	3.8760	3.8761	3.8761	3.8755	3.8758	3.8760
	Before	3.8756	3.8755	3.8756	3.8750	3.8754	3.8756
	Δ	.0004	.0006	.0005	.0005	.0004	.0004
3.	After	3.8756	3.8758	3.8758	3.8756	3.8758	3.8759
	Before	3.8752	3.8754	3.8754	3.8751	3.8754	3.8754
	Δ	.0004	.0004	.0004	.0005	.0004	.0005

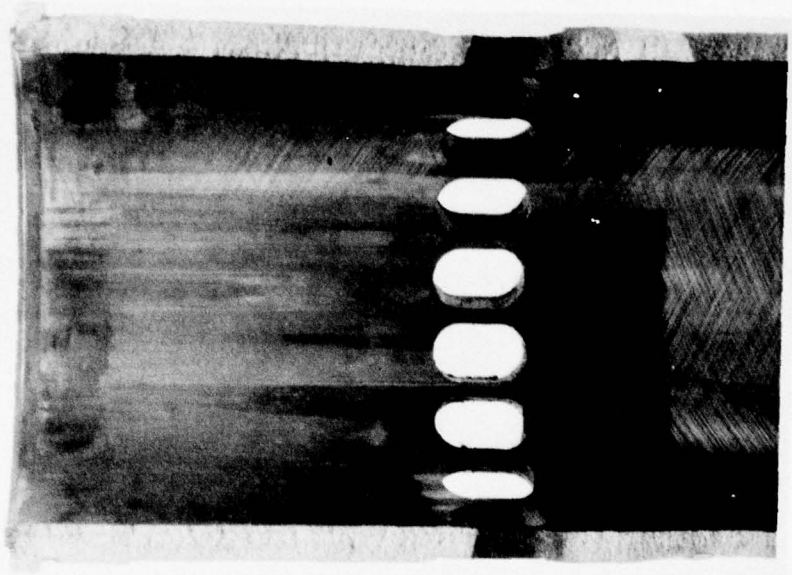
Average (All) 0.0004 IN
Average T/AT 0.0004 IN

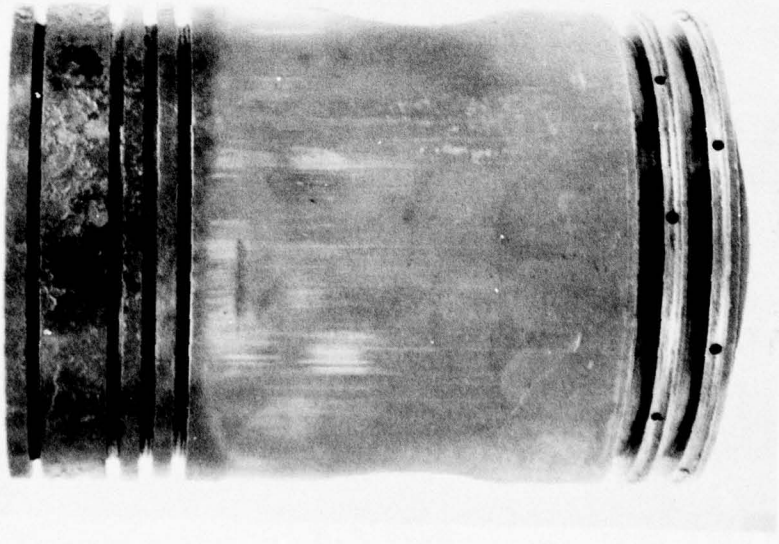
PISTON RING GAP (IN)
TEST #5

Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	.035	.031	.033	.035	.030	.025	.025	.023
	Before	.034	.033	.033	.036	.025	.023	.022	.020
	Δ	.001	(.002)	0	(.001)	.005	.002	.003	.003
2.	After	.044	.032	.032	.032	.026	.026	.026	.025
	Before	.041	.032	.033	.032	.024	.024	.024	.023
	Δ	.003	0	(.001)	0	.002	.002	.002	.002
3.	After	.039	.030	.031	.032	.020	.018	.026	.027
	Before	.035	.030	.031	.032	.020	.017	.023	.024
	Δ	.004	0	0	0	0	.001	.003	.003

Avg F/R (#1) Wear 0.003 IN

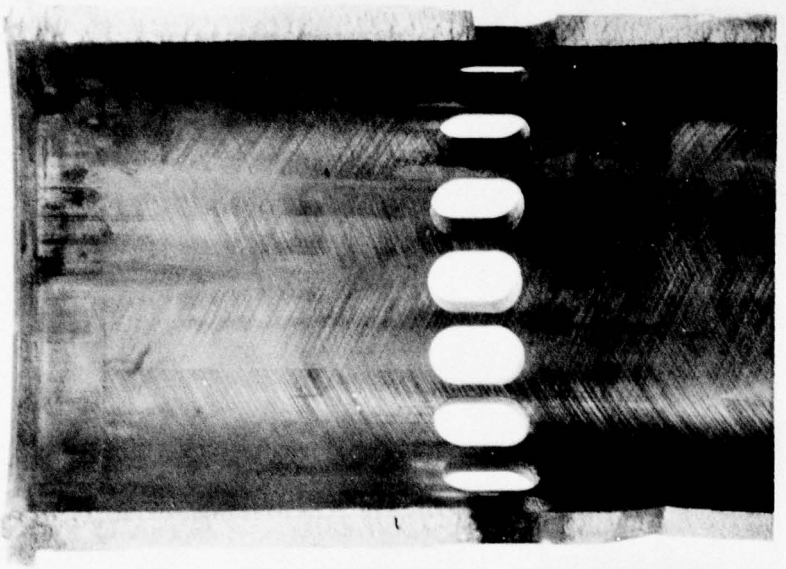
PISTON AND CYLINDER LINER CONDITION
Test #5

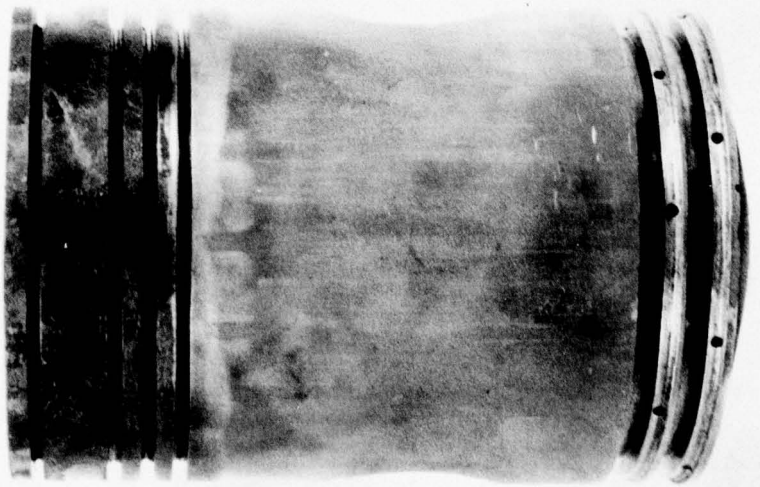




No. 3 - Antithrust Side
(worst)

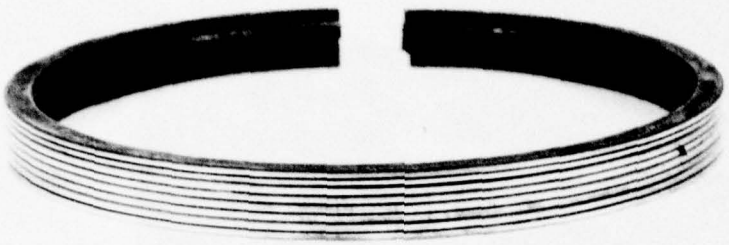
PISTON AND CYLINDER LINER CONDITION
Test #5



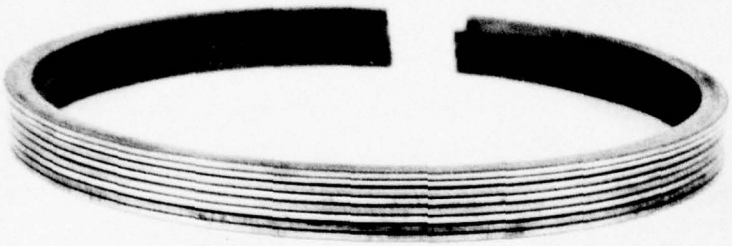


No. 3 - Thrust Side
(Best)

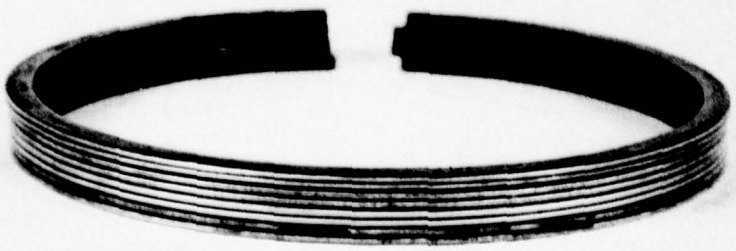
RING FACE CONDITION
Test #5



Piston - 1



Piston - 2



Piston - 3

APPENDIX D

3-53 TEST #6

FUEL: 1% S, DF-2

LUBE: AL-6856 (MC-520)

START: 9 May 1977

END: 27 May 1977

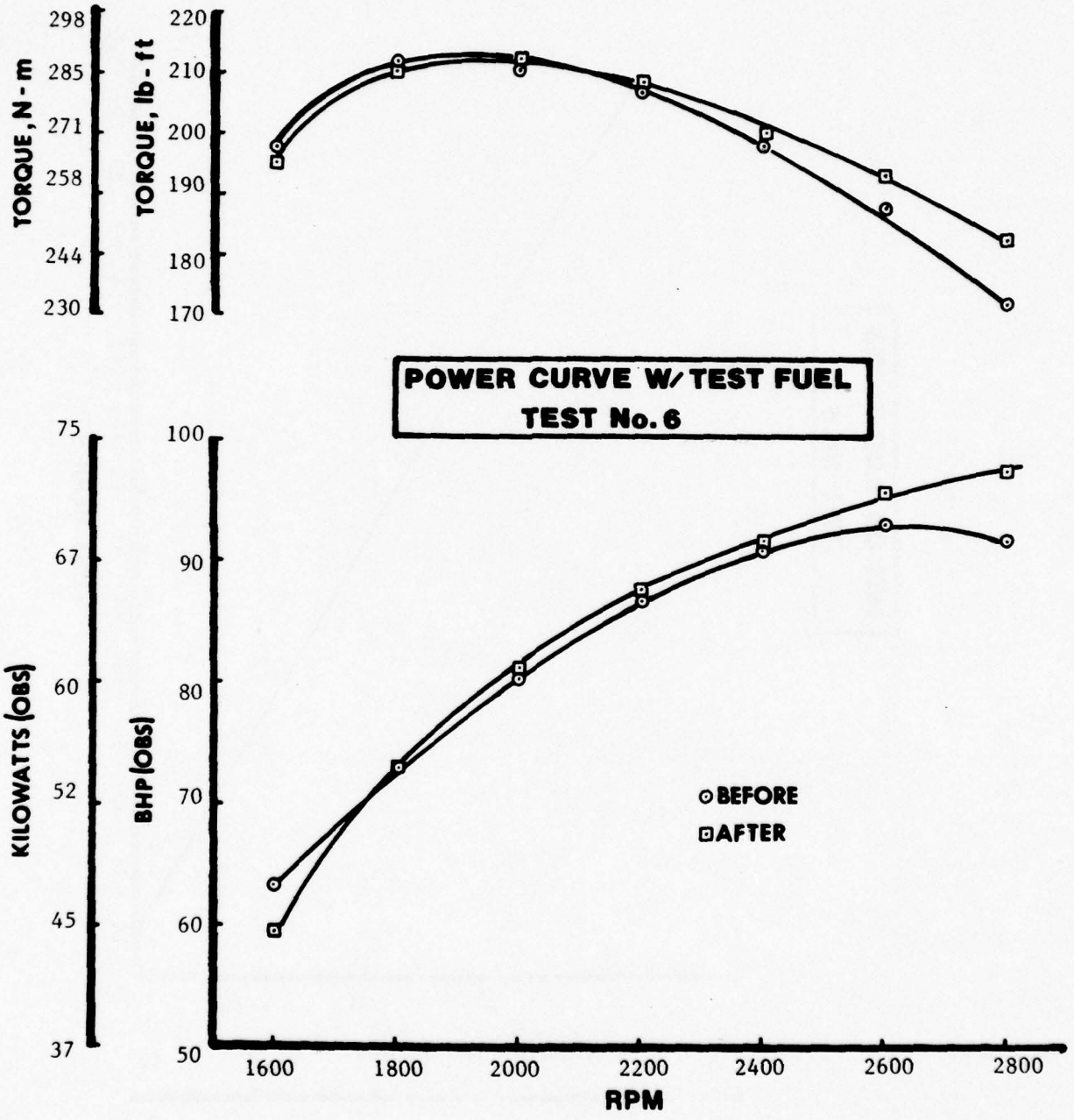
ENGINE OPERATING DATA (AVG)
TEST #6

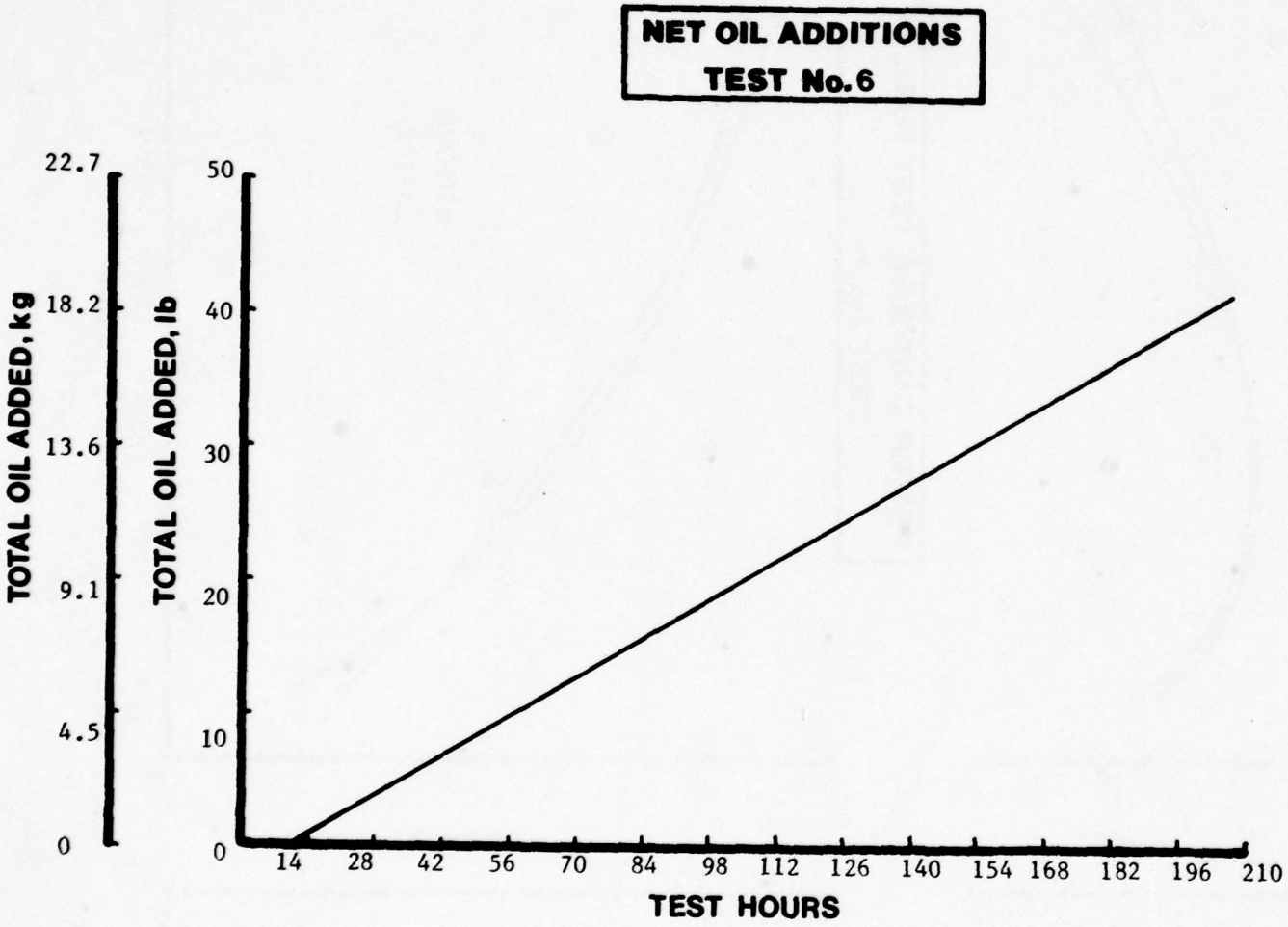
	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2797	2806	2801	651
Load, lbs	97	106	104	
Torque, lb-ft	170	186	181	
BHp obs	90	99	97	
Fuel Rate, lb/hr	41.0	44.8	44.1	
BMEP, psi	81	88	86	
BSFC lb/BHp-hr	0.443	0.468	0.457	
Temperatures, °F				
Jacket Coolant-In	194	196	196	94
Jacket Coolant-Out	204	205	204	100
Oil Sump	248	252	250	
Inlet Air (Blower)	74	86	82	
Exhaust Manifold	950	975	965	
Fuel @ Return	146	151	148	
Pressures				
Oil Gallery, psig	43	45	44	30
Blower Discharge, psig	8.4	8.7	8.6	
Intake Vacuum, in. H_2O	7.0	7.1	7.0	
Crankcase, in. H_2O	0.21	0.22	0.22	
Exhaust, Common, in. Hg	2.9	3.1	3.0	

LUBRICANT ANALYSES
TEST #6

Property	ASTM Method	New Oil	70 Hrs	140 Hrs	210 Hrs
K. Vis, cS, 38°C (100°F)	D445	121.0	143.7	164.3	173.5
K. Vis, cS, 99°C (210°F)	D445	12.0	13.9	14.9	15.5
VI	D2270	101	---	---	---
TAN	D664	2.3	2.9	3.3	3.8
TBN	D2896	13.9	11.0	11.1	12.1
Insolubles, wt%	D893				
Pentane A		0.04	---	---	0.07
Benzene A		0.04	---	---	0.01
Pentane B		0.03	---	---	0.83
Benzene B		0.01	---	---	0.73
API Gravity, °	D287	25.5	---	---	24.3
Pour Point, °C	D97	-17	---	---	---
Flash Point, °C	D92	223	---	---	221
Carbon Residue, wt%	D524	2.10	3.01	3.64	3.79
Sulfated Ash, wt%	D874	1.64	1.77	1.96	2.03
Elemental	Method				
Ba, ppm	AA	< 50	---	---	---
Mg, ppm	AA	26	---	---	---
Ca, wt%	AA/XRF	.44/.46	---	---	---
Zn, wt%	AA	.07/.08	---	---	---
Na, ppm	AA	10	---	---	19
Cu, ppm	XRF	---	---	---	7
Cr, ppm	AA	---	---	---	8
Pb, ppm	AA	---	---	---	16
Sn, ppm	AA	---	---	---	< 50
Fe, ppm	XRF	---	70	75	90

--- = Not Determined.
AA = Atomic Absorption.
XRF = X-Ray Fluorescence.


TORQUE, N - m
298
285
271
258
244
230
TORQUE, lb - ft
220
210
200
190
180
170
POWER CURVE W/ TEST FUEL
TEST No. 6
KILOWATTS (OBS)
75
67
60
52
45
37
BHP (OBS)
100
90
80
70
60
50
1600
1800
2000
2200
2400
2600
2800
RPM
⊙ BEFORE
⊡ AFTER


NET OIL ADDITIONS
TEST No. 6
TOTAL OIL ADDED, kg
22.7
18.2
13.6
9.1
4.5
0
TOTAL OIL ADDED, lb
50
40
30
20
10
0
14
28
42
56
70
84
98
112
126
140
154
168
182
196
210
TEST HOURS

RING FACE CONDITION: % BURNING
TEST #6

	Cylinder Number		
	1	2	3
First Ring	3	50	2
Second Ring	40	95	90
Third Ring	30	70	50
Fourth Ring	10	50	75
Average of all	48%		

RING STICKING
TEST #6

Ring No.	Piston Number		
	1	2	3
1	Sluggish	30% Cold Stuck	Sluggish
2	F	F	F
3	F	F	F
4	F	F	F

F = Free

CYLINDER LINERS
TEST #6

Cylinder Liner Scuffing
Percent of Compression Ring
Travel Area

Cylinder Number	Percent Port Restriction	Percent Scuffed		% Total Area Scuffed	% Glazed	% Lacquer
		Thrust	Anti-Thrust			
1	5	18	30	24	10	90
2	3	5	85	45	0	100
3	3	5	55	30	0	90
Average	4	9	57	33	3	97

PISTON O.D. (IN)
TEST #6

Cylinder	1	2	3
After	3.8712	3.8712	3.8712
Before	3.8712	3.8720	3.8718
Δ	0	.0008	.0006

PISTON SURFACE CONDITION
TEST #6

	Piston Number		
	1	2	3
Top Land	N	N	N
Skirt	Lt. Scuff-T. Lt. Scratch	Very Heavy Scratch	Lt. Scuff-AT Lt. Scratch
Piston Pin	N	N	N

N = Normal

PISTON GROOVE INSIDE DIAMETER - % RING SUPPORTING CARBON
TEST #6

Piston Ring	Quadrant	Piston Number 1	2	3
1	1	100	100	95
	2	0	0	0
	3	0	0	0
	4	0	0	0
2	1	0	10	0
	2	50	0	15
	3	40	100	100
	4	0	20	0

Quadrants:

1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #6

Area	Cylinder No. 1	2	3
Head	All 90%- AHC		
Face	All 100%-9		
Tulip	All 100%-9		
Stem	All Normal		

EXHAUST VALVE SURFACE CONDITIONS
TEST #6

	Cylinder No. 1	2	3
Freeness in Guide	F	F	F
Head	N	N	N
Face	All very heavy to heavy pitting*		
Seat	N	N	N
Stem	N	N	N
Tip	N	N	N

N = Normal
F = Free
*1 valve each cylinder leaking due to face build-up.
Cyl-3 also one valve channeled on face and leaking.

RING DEPOSITS
TEST #6

Cylinder Number	Ring	1 CARB	1 LACQ	2 CARB	2 LACQ	3 CARB	3 LACQ
Top	1	70 AHC	25-9 5-7	60-1/2 AHC	40-9	100-1/2 AHC	0
	2	0	40-7 60-6	0	30-8 70-7	0	20-9 30-8 50-7
	3	0	20-4 80-2	0	5-8 95-6	0	70-4 30-3
	4	0	100-3	0	100-3	0	100-3
ID	1	100-1/2 AHC	0	100-1/2 AHC	0	100-1/2 AHC	0
	2	100-1/2 AHC	0	100-1/2 AHC	0	100-1/2 AHC	0
	3	100-1/2 AHC	0	100-1/2 AHC	0	100-1/2 AHC	0
	4	0	100-9	0	100-9	0	100-9
Bottom	1	0	100-2	0	100-2	0	5-9 95-2
	2	0	5-5 95-2	0	50-3 50-4	0	10-4 90-2
	3	0	100-3	0	100-4	0	10-7 90-3
	4	0	60-4 40-2	0	100-3	0	100-4

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-6856
MC 520

RATER E.R. Lyons DATE 6-2-77
LABORATORY TEST NUMBER 3-53-6
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1% S, DF-2

PISTON NO. 1

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	452

DEPOSIT TYPE	DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON HC	1.00	80	80.00	25	75.00	40	40.00			25	25.00	75	75.00	35	35.00				
CARBON MHC	0.75	20	15.00	25	18.75														
CARBON MC	0.50					25	12.50												
CARBON LC	0.25					35	8.75	35	8.75	75	18.75	25	6.25	10	2.50	10	2.50		
CARBON VLC	0.15																		
CARBON RATING		95.00		93.75		61.25		8.75		43.75		81.25		37.50		2.50			
LACQUER BL	0.100							65	6.50					55	5.50	55	5.50	100	10.00
LACQUER DBrL	0.075																		
LACQUER AL	0.050															35	.875		
LACQUER LAL	0.025																		
LACQUER VLAL	0.010																		
LACQUER RL	0.001																		
LACQUER RATING								6.50						5.50		6.375		10.00	
CLEAN	0																		
ZONAL RATING																			
LOCATION FACTOR																			
WEIGHTED RATING		95.00		93.75		61.25		15.25		43.75		81.25		43.00		8.875		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-6856
MC 520

RATER E.R. Lyons DATE 6-2-77
LABORATORY TEST NUMBER 3-53-6
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1% S, DF-2

PISTON NO. 2

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	494

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES								LANDS								UNDER-CROWN	
			NO. 1		NO. 2		NO. 3		NO. 4		NO. 1		NO. 2		NO. 3		NO. 4			
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00	100	100.00	90	90.00	25	25.00			80	50.00	80	80.00	50	50.00				
	MHC	0.75			10	7.50														
	MC	0.50					25	12.50												
	LC	0.25					50	12.50	35	8.75	50	12.50	10	2.50	50	12.50	30	7.50		
	VLC	0.15																		
	CARBON RATING		100.00		97.50		50.00		8.75		62.50		82.50		62.50		7.50			
LACQUER	BL	0.100							65	6.50			10	1.00			45	4.50	100	10.00
	DBrL	0.075																		
	AL	0.050															25	1.25		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING								6.50				1.00				5.75		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			100.00		97.50		50.00		15.25		62.50		83.50		62.50		13.25		10.00	

*WEIGHTED TOTAL DEPOSITS

77

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-6856
MC 520

RATER E.R. Lyons DATE 6-2-77
LABORATORY TEST NUMBER 3-53-6
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1% S, DF-2

PISTON NO. 3

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	426

DEPOSIT TYPE	DEPOSIT FACTOR	GROOVES NO. 1		GROOVES NO. 2		GROOVES NO. 3		GROOVES NO. 4		LANDS NO. 1		LANDS NO. 2		LANDS NO. 3		LANDS NO. 4		UNDER-CROWN	
		AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON																			
HC	1.00	100	100.00	55	55.00	35	35.00			25	25.00	55	55.00	50	50.00	15	15.00		
MHC	0.75																		
MC	0.50					10	5.00												
LC	0.25			45	11.25	55	13.75	40	10.00	75	18.75	15	3.75			10	2.50		
VLC	0.15																		
CARBON RATING		100.00		66.25		53.75		10.00		43.75		58.75		50.00		17.50			
LACQUER																			
BL	0.100							60	6.00			25	2.50	15	1.50	30	3.00	100	10.00
DBrL	0.075																		
AL	0.050											5	.25	10	.50	5	.25		
LAL	0.025													25	.625	40	1.00		
VLAL	0.010																		
RL	0.001																		
LACQUER RATING								6.00				2.75		2.625		4.25		10.00	
CLEAN	0																		
ZONAL RATING																			
LOCATION FACTOR																			
WEIGHTED RATING		100.00		66.25		53.75		16.00		43.75		61.50		52.625		21.75		10.00	

*WEIGHTED TOTAL DEPOSITS

CYLINDER LINER I.D. (IN)
TEST #6

Cylinder No.		Front/Back Parallel to Crank Top	Middle	Bottom	Thrust/Antithrust Perpendicular to Crank Top	Middle	Bottom
1.	After	3.8766	3.8770	3.8777	3.8780	3.8782	3.8781
	Before	3.8766	3.8767	3.8771	3.8765	3.8768	3.8771
	Δ	0	0.0003	0.0006	0.0015	0.0014	0.0010
2.	After	3.8766	3.8769	3.8773	3.8780	3.8786	3.8780
	Before	3.8763	3.8765	3.8769	3.8763	3.8765	3.8770
	Δ	0.0003	0.0004	0.0004	0.0017	0.0021	0.0010
3.	After	3.8757	3.8761	3.8768	3.8774	3.8772	3.8766
	Before	3.8757	3.8759	3.8763	3.8755	3.8757	3.8759
	Δ	0	0.0002	0.0005	0.0009	0.0015	0.0007

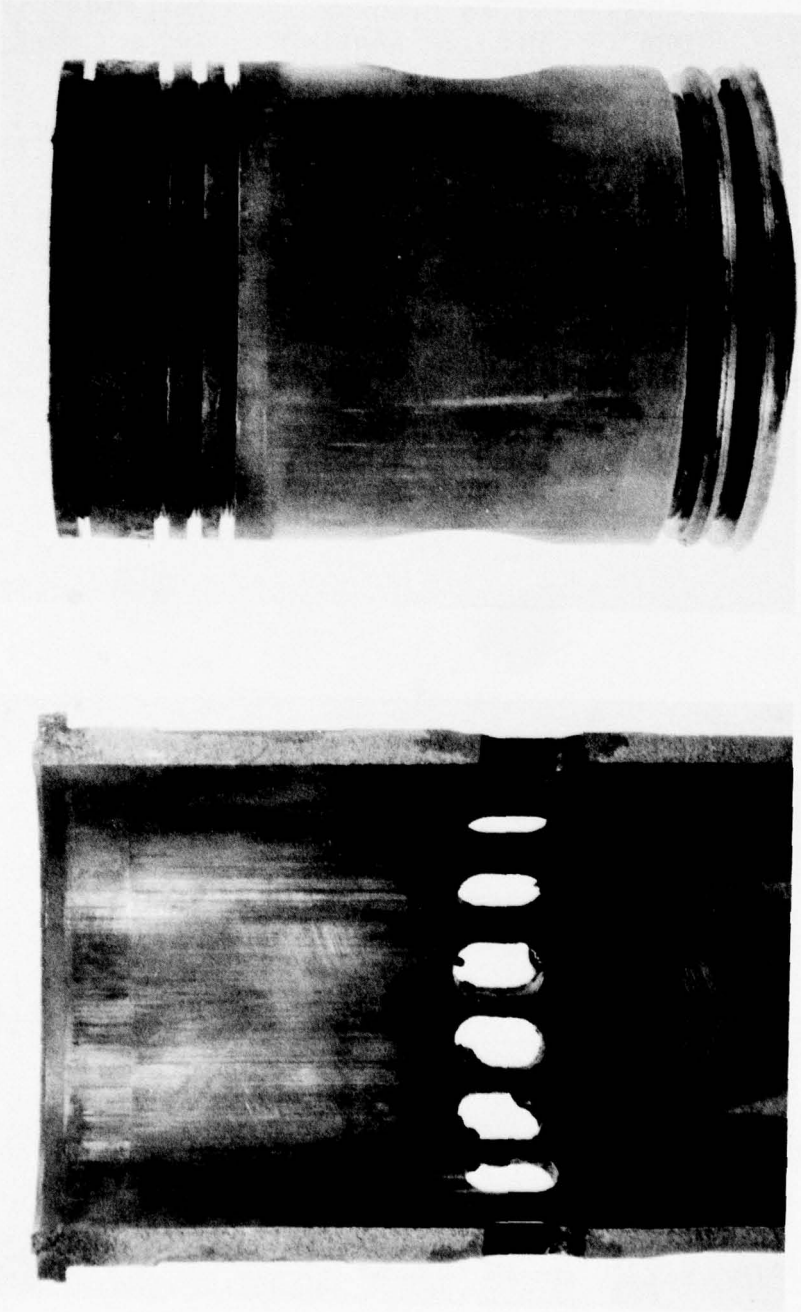
Average (All) 0.0008 IN
Average T/AT 0.0013 IN

PISTON RING GAP (IN)
TEST #6

Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	0.036	0.032	0.028	0.027	0.022	0.023	0.022	0.022
	Before	0.034	0.032	0.028	0.027	0.020	0.022	0.022	0.022
	Δ	.002	0	0	0	.002	.001	0	0
2.	After	0.033	0.035	0.032	0.028	0.021	0.023	0.022	0.023
	Before	0.033	0.034	0.032	0.027	0.020	0.022	0.022	0.022
	Δ	0	0.001	0	0.001	.001	.001	0	.001
3.	After	0.037	0.025	0.025	0.027	0.021	0.022	0.022	0.021
	Before	0.035	0.025	0.025	0.026	0.020	0.021	0.021	0.021
	Δ	.002	0	0	0.001	.001	.001	.001	0

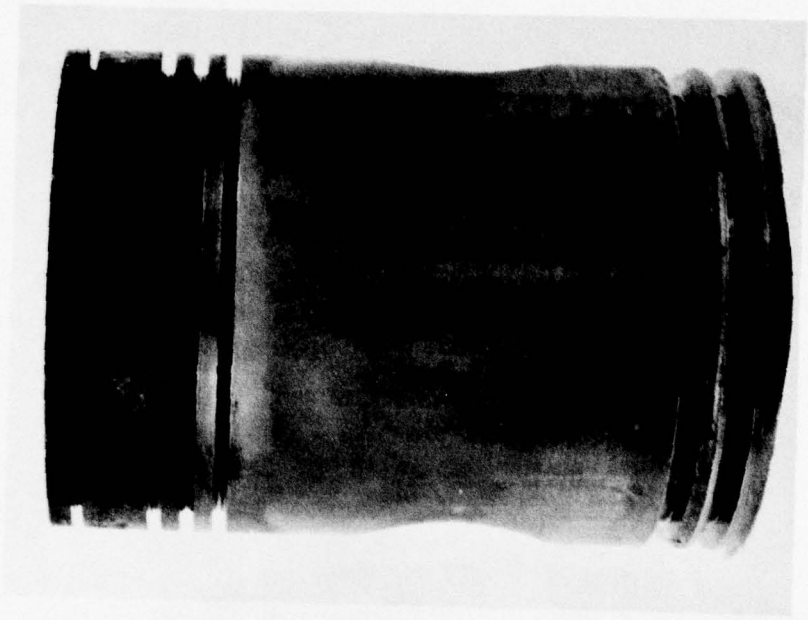
Avg F/R (#1) Wear 0.001 IN

PISTON AND CYLINDER LINER CONDITION
Test #6

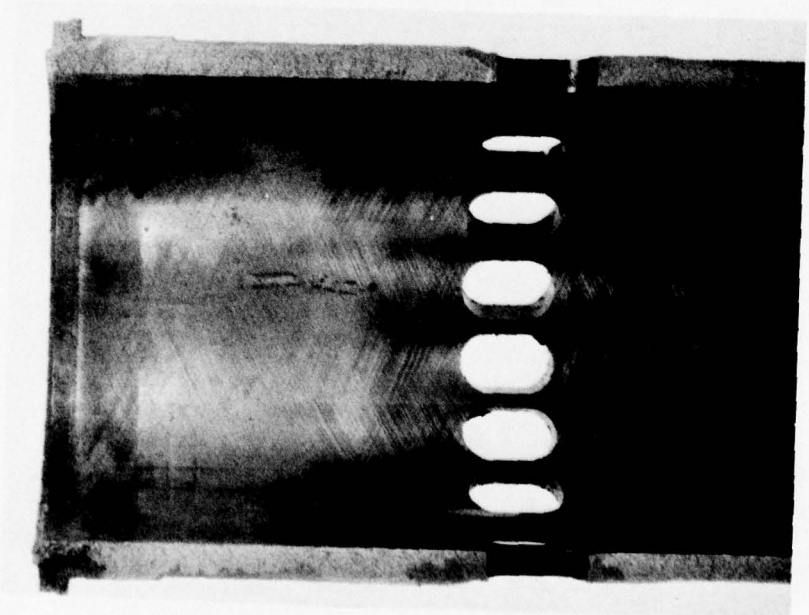


No. 2 Antithrust Side
(worst)

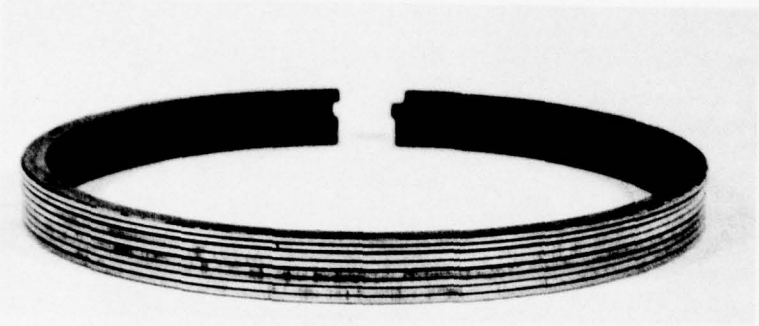
PISTON AND CYLINDER LINER CONDITION
Test #6



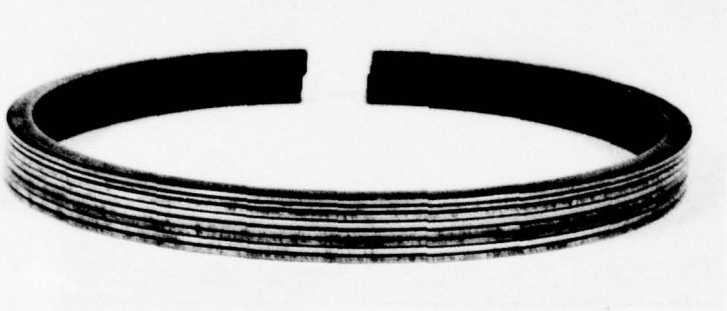
No. 2 - Thrust Side
(best)



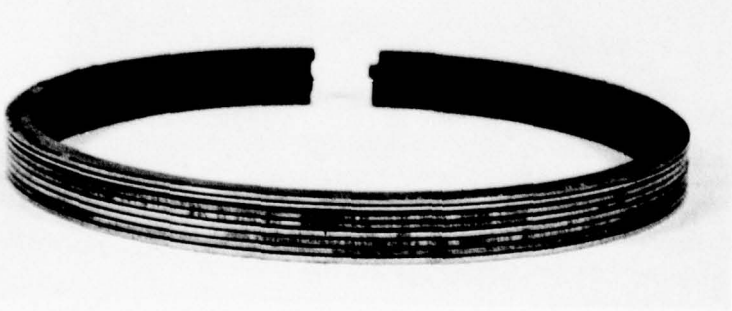
RING FACE CONDITION
Test #6



Piston - 1



Piston - 2



Piston - 3

APPENDIX E

3-53 TEST #11

FUEL: 1% S, DF-2

LUBE: AL-6942

START: 29 NOVEMBER 1977

END: 20 DECEMBER 1977

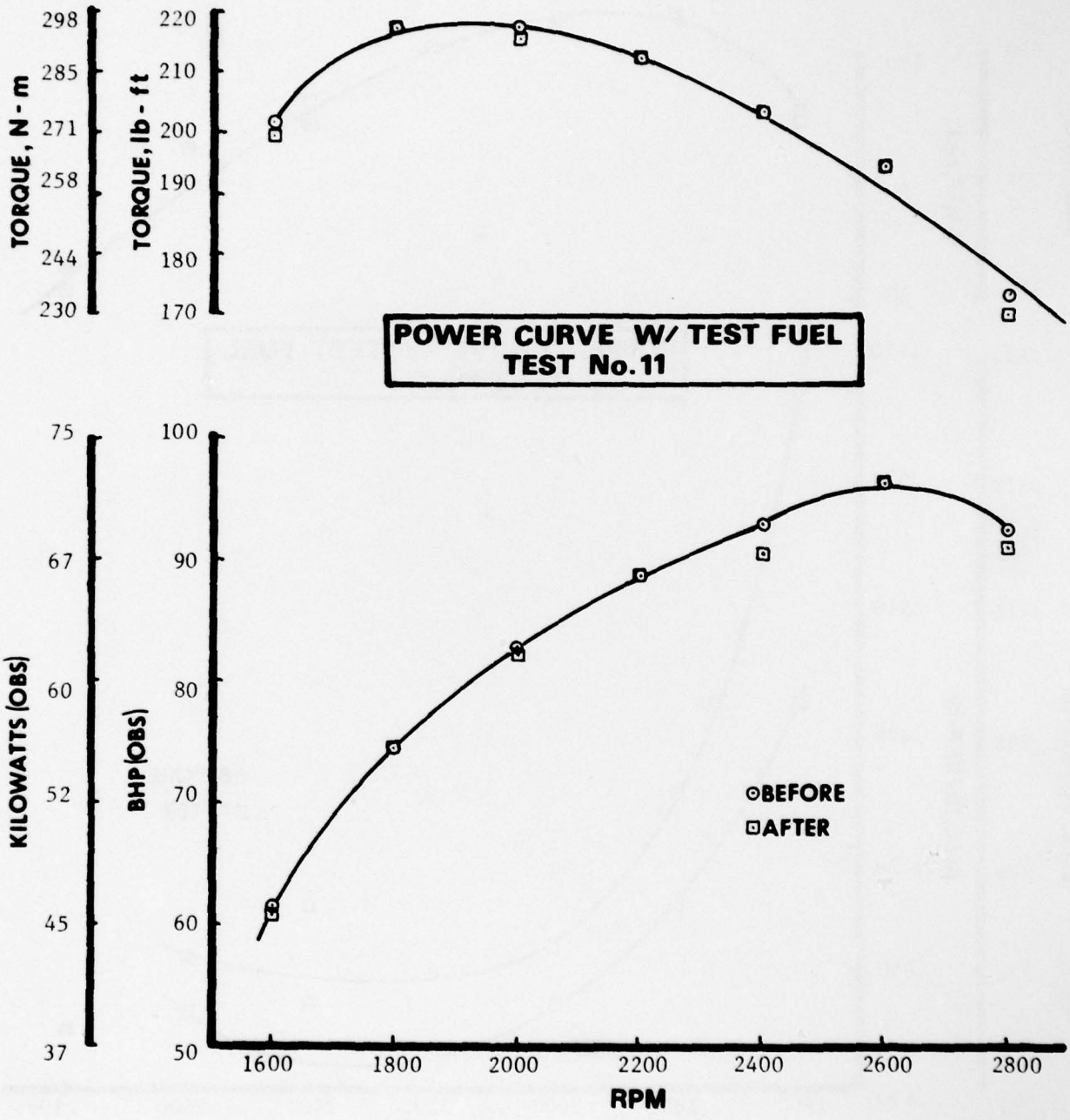
ENGINE OPERATING DATA (AVG)
TEST #11

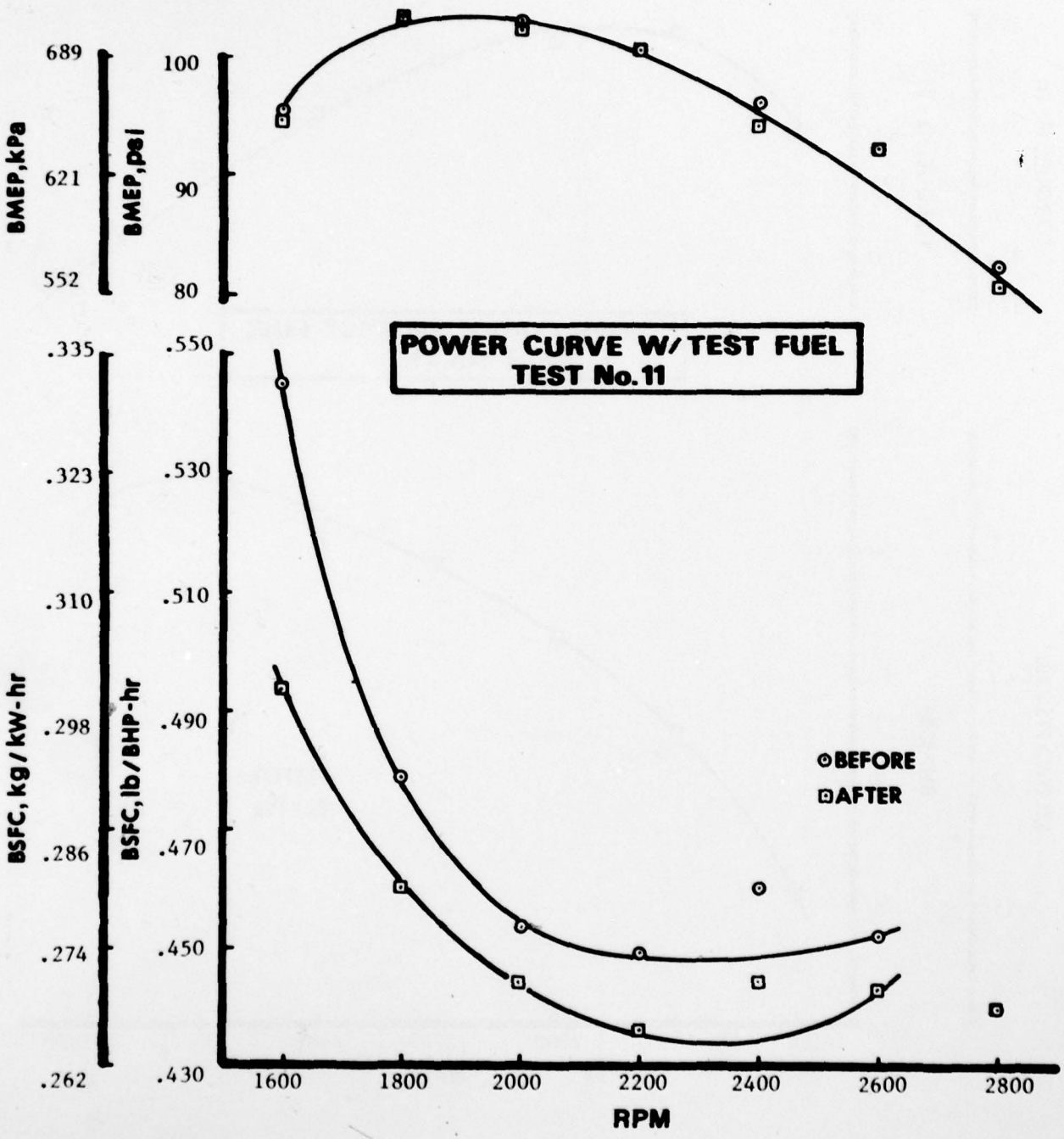
	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2798	2803	2801	649
Load, lbs	94	99	97	
Torque, lb-ft	165	173	169	
BHp obs	88	92	90	
Fuel Rate, lb/hr	35.6	40.8	39.7	
BMEP, psi	78	82	80	
BSFC lb/BHp-hr	0.385	0.484	0.441	
Temperatures, °F				
Jacket Coolant-In	196	197	197	95
Jacket Coolant-Out	204	205	205	100
Oil Sump	240	248	244	
Inlet Air (Blower)	60	82	74	
Exhaust Manifold	895	940	919	
Fuel @ Return	138	149	144	
Fuel @ Filter	81	94	90	
Pressures				
Oil Gallery, psig	45	45	45	
Blower Discharge, psig	4.3	4.6	4.4	
Intake Vacuum, in. H_2O	6.9	7.2	7.0	
Crankcase, in. H_2O	0.28	0.33	0.30	
Exhaust, Common, in. Hg	2.8	3.0	2.9	

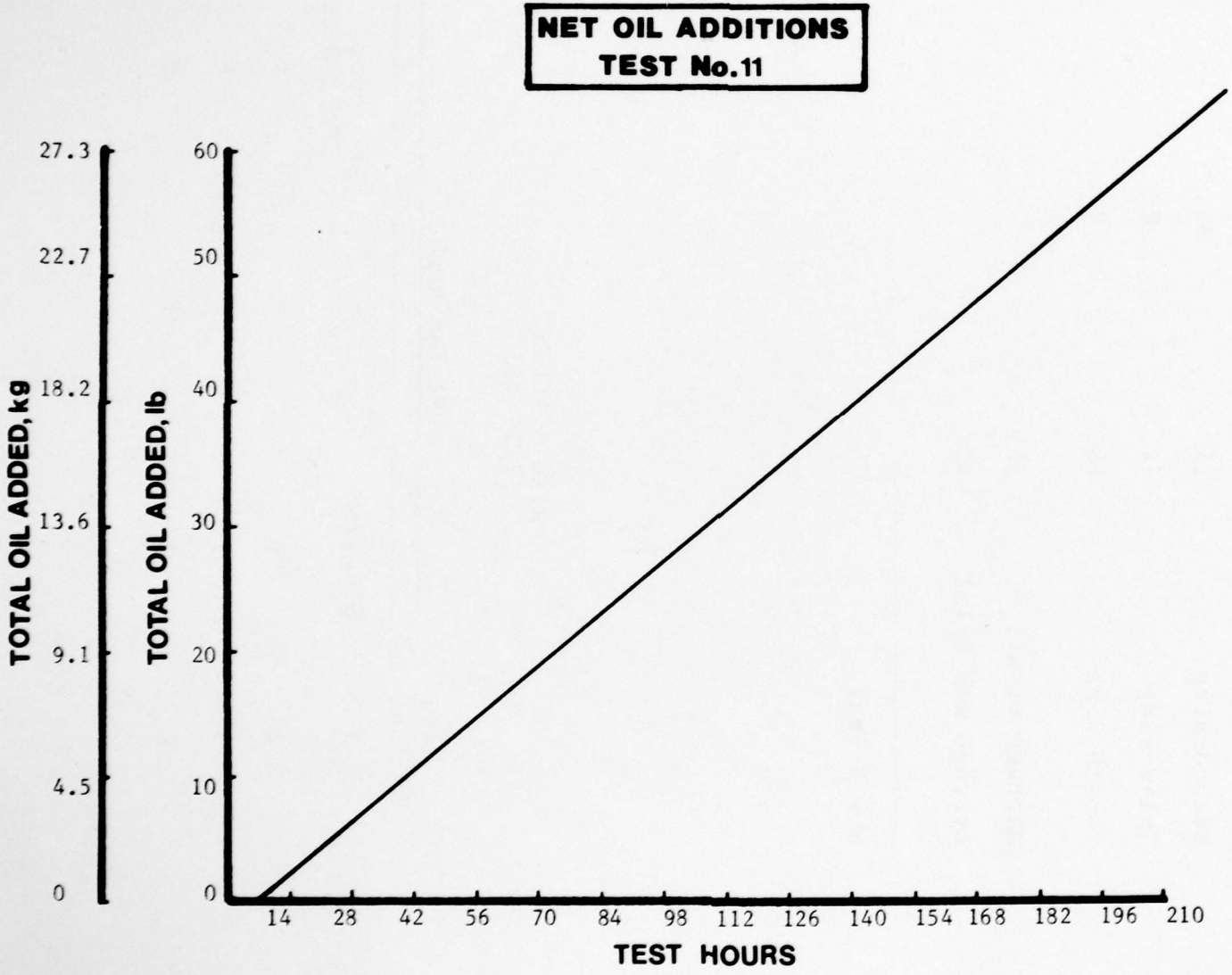
LUBRICANT ANALYSES (AL-6942)
TEST #11

Property	ASTM Method	New Oil	70 Hrs	140 Hrs	210 Hrs
K. Vis, cS, 40°C	D445	61.3	70.1	74.3	75.3
K. Vis, cS, 100°C	D445	10.2	11.3	11.7	11.8
VI	D2270	153	151	151	151
TAN	D664	3.7	3.9	4.7	4.7
TBN	D2896	10.2	9.2	9.2	9.2
Insolubles, wt%	D893				
Pentane A		0.09	0.02	0.03	0.03
Benzene A		0.01	0.02	0.02	0.02
Pentane B		0.09	0.03	0.03	0.03
Benzene B		0.02	0.02	0.03	0.02
API Gravity, °	D287	21.9	21.3	21.2	20.8
Pour Point, °C	D97	-41	---	---	---
Flash Point, °C	D92	227	229	232	232
Carbon Residue, wt%	D524	1.53	1.92	2.08	2.14
Sulfated Ash, wt%	D874	1.50	1.59	1.67	1.69
Elemental	Method				
Ba, ppm	AA	< 50	---	---	---
Mg, ppm	AA	11	---	---	---
Ca, wt%	AA/XRF	.38/.33	0.38	0.41	0.42
Zn, wt%	AA/XRF	.18/.16	0.18	0.19	0.19
Na, ppm	AA	10	---	---	---
Cu, ppm	XRF	---	6	7	6
Cr, ppm	AA	---	< 5	< 5	< 5
Pb, ppm	AA	---	8	12	11
Fe, ppm	AA/XRF	---	50/40	57/60	61/60

--- = Not Determined.
AA = Atomic Absorption.
XRF = X-Ray Fluorescence.


TORQUE, N - m
298
285
271
258
244
230
TORQUE, lb - ft
220
210
200
190
180
170
POWER CURVE W/ TEST FUEL
TEST No. 11
KILOWATTS (OBS)
75
67
60
52
45
37
BHP (OBS)
100
90
80
70
60
50
⊙BEFORE
⊡AFTER
1600
1800
2000
2200
2400
2600
2800
RPM


POWER CURVE W/ TEST FUEL
TEST No. 11
BMEP, kPa
BMEP, psi
689
621
552
100
90
80
BSFC, kg / kW-hr
BSFC, lb / BHP-hr
.335
.323
.310
.298
.286
.274
.262
.550
.530
.510
.490
.470
.450
.430
BEFORE
AFTER
1600
1800
2000
2200
2400
2600
2800
RPM


NET OIL ADDITIONS
TEST No.11
TOTAL OIL ADDED, kg
27.3
22.7
18.2
13.6
9.1
4.5
0
TOTAL OIL ADDED, lb
60
50
40
30
20
10
0
14
28
42
56
70
84
98
112
126
140
154
168
182
196
210
TEST HOURS

RING FACE CONDITION: % BURNING
TEST #11

	Cylinder Number		
	1	2	3
First Ring	15	5	25
Second Ring	15	25	20
Third Ring	50	N	75
Fourth Ring	55	10	80
Average of all	31%		
Average w/o Cyl-2	42%		

N = Normal

RING STICKING
TEST #11

Ring No.	Piston Number		
	1	2	3
1	Sluggish	F	80% Cold Stuck
2	F	F	F
3	F	F	F
4	F	F	F

F = Free

CYLINDER LINERS
TEST #11

Cylinder Liner Scuffing
Percent of Compression Ring
Travel Area

Cylinder Number	Percent Port Restriction	Percent Scuffed		% Total Area Scuffed	% Glazed	% Lacquer
		Thrust	Anti-Thrust			
1	< 1	10	30	20	0	100
2	< 1	20	5	13	5	95
3	< 1	10	80	45	0	100
Average	< 1	13	38	26	2	98

PISTON O.D. (IN)
TEST #11

Cylinder	1	2	3
Before	3.8715	3.8705	3.8715
After	3.8715	3.8700	3.8715
Δ	0	.0005	0

PISTON SURFACE CONDITION
TEST #11

	Piston Number		
	1	2	3
Top Land	N	N	N
Skirt	10% plate melt-T. 5% plate melt-AT. Lt. Scratch	15% plate melt-T. Lt. Scratch	N
Piston Pin	N	N	N

PISTON GROOVE INSIDE DIAMETER - % RING SUPPORTING CARBON
TEST #11

Piston Ring	Quadrant	Piston Number 1	2	3
1	1	15	0	5
	2	75	0	45
	3	70	15	0
	4	0	5	25
2	1	5	90	0
	2	10	0	0
	3	80	0	0
	4	5	0	0

Quadrants:

1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #11

Area	Cylinder No. 1	2	3
Head	All 65%-AHC to Soot, Heavier Than Usual		
Face	All Heavy Deposit		
Tulip	All Heavier Deposit Than Usual		
Stem	All 100%-9 to Clean		

EXHAUST VALVE SURFACE CONDITIONS
TEST #11

	Cylinder No. 1	2	3
Freeness in Guide	F	F	F
Head	N	N	N
Face	*	*	*
Seat	N	N	N
Stem	N	N	N
Tip	N	N	N

*Heavier deposit than normal, some leak marks appearing.

RING DEPOSITS
TEST #11

Cylinder Number		1		2		3	
	Piston	CARB	LACQ	CARB	LACQ	CARB	LACQ
Top	1	20-1/2 AHC	30-6 50-5	80-AHC 20-1/2 AHC	0	30-AHC	5-9, 55-5 10-6
	2	0	25-9 50-6, 25-5	0	20-9 20-8, 60-7	0	15-9 25-7, 60-6
	3	0	100-6	0	100-5	0	100-6
	4	0	100-3	0	100-2	0	100-2
ID	1	100-AHC	0	100-1/2 AHC	0	100-1/2 AHC	0
	2	100-AHC	0	100-1/2 AHC	0	100-AHC	0
	3	100-1/2 AHC	0	100-1/2 AHC	0	100-1/2 AHC	0
	4	0	100-9	0	100-8	0	100-8
Bottom	1	0	100-2	0	30-8, 20-7 25-4, 25-5	0	40-6 60-4
	2	0	30-7 70-3	0	50-6 50-4	0	50-4 50-3
	3	0	100-2	0	100-3	0	20-7 80-3
	4	0	100-2	0	100-2	0	100-3

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-6942

RATER E.R. Lyons DATE 12-21-77
LABORATORY TEST NUMBER 3-53-11
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1%S DF-2

PISTON NO. 1

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	446

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	GROOVES NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	GROOVES NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	GROOVES NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	GROOVES NO. 4 DEMERIT	LANDS NO. 1 AREA-%	LANDS NO. 1 DEMERIT	LANDS NO. 2 AREA-%	LANDS NO. 2 DEMERIT	LANDS NO. 3 AREA-%	LANDS NO. 3 DEMERIT	LANDS NO. 4 AREA-%	LANDS NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00	100	100.0	80	80.00					80	80.00	85	85.00						
	MHC	0.75			20	15.0					15	11.25	10	7.50						
	MC	0.50																		
	LC	0.25					50	12.50	60	15.00	5	1.25	5	1.25	20	5.00				
	VLC	0.15					30	4.50												
	CARBON RATING		100.00		95.00		17.00		15.00		92.50		93.75		5.00					
LACQUER	BL	0.100					20	2.00							70	7.00	60	6.00		
	DBrL	0.075							40	3.00									100	7.50
	AL	0.050													5	.25	20	1.00		
	LAL	0.025													5	.125	20	.50		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING						2.00		3.00						7.38		7.50		7.50	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			100.00		95.00		19.00		18.00		92.50		93.75		12.38		7.50		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-6942

RATER E.R. Lyons DATE 12-21-77
LABORATORY TEST NUMBER 3-53-11
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1% S DF-2

PISTON NO. 2

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	370

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES								LANDS								UNDER-CROWN	
			NO. 1		NO. 2		NO. 3		NO. 4		NO. 1		NO. 2		NO. 3		NO. 4			
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00	50	50.00	80	80.00					25	25.00	45	45.00						
	MHC	0.75			20	15.00	50	37.50					20	15.00						
	MC	0.50																		
	LC	0.25	50	12.50			50	12.50	20	5.00	75	18.75	20	5.00	100	25.00				
	VLC	0.15																		
	CARBON RATING		62.50		95.00		50.00		5.00		43.75		65.00		25.00					
LACQUER	BL	0.100							80	8.00			15	1.50			50	5.00		
	DBrL	0.075																	100	7.50
	AL	0.050															20	1.00		
	LAL	0.025															30	.75		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING								8.00				1.50				6.75		7.50	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			62.50		95.00		50.00		13.00		43.75		66.50		25.00		6.75		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-6942

RATER E.R. Lyons DATE 12-21-77
LABORATORY TEST NUMBER 3-53-11
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1% S DF-2

PISTON NO. 3

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	363

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	GROOVES NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	GROOVES NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	GROOVES NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	GROOVES NO. 4 DEMERIT	LANDS NO. 1 AREA-%	LANDS NO. 1 DEMERIT	LANDS NO. 2 AREA-%	LANDS NO. 2 DEMERIT	LANDS NO. 3 AREA-%	LANDS NO. 3 DEMERIT	LANDS NO. 4 AREA-%	LANDS NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00	100	100.00	30	30.00					50	50.00	90	90.00						
	MHC	0.75																		
	MC	0.50			20	10.00	40	20.00												
	LC	0.25			50	12.50					50	12.50	10	2.50	10	2.50				
	VLC	0.15																		
	CARBON RATING		100.00		52.50		20.00				62.50		92.50		2.50					
LACQUER	BL	0.100					60	6.00							80	8.00	25	2.50		
	DBrL	0.075							30	2.25					10	.75			100	7.50
	AL	0.050							70	3.50							10	.50		
	LAL	0.025															65	1.625		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING						6.00		5.75						8.75		4.625		7.50	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			100.00		52.50		26.00		5.75		62.50		92.50		11.25		4.625		7.50	

*WEIGHTED TOTAL DEPOSITS

CYLINDER LINER I.D. (IN)
TEST #11

Cylinder No.		Front/Back Parallel to Crank			Thrust/Antithrust Perpendicular to Crank		
		Top	Middle	Bottom	Top	Middle	Bottom
1.	After	3.8767	3.8768	3.8772	3.8769	3.8770	3.8770
	Before	3.8761	3.8762	3.8764	3.8759	3.8758	3.8762
	Δ	.0006	.0006	.0008	.0010	.0012	.0008
2.	After	3.8770	3.8768	3.8771	3.8768	3.8771	3.8772
	Before	3.8761	3.8761	3.8764	3.8760	3.8761	3.8763
	Δ	.0009	.0007	.0007	.0008	.0010	.0009
3.	After	3.8765	3.8766	3.8769	3.8769	3.8774	3.8770
	Before	3.8757	3.8759	3.8762	3.8758	3.8760	3.8761
	Δ	.0008	.0007	.0007	.0011	.0014	.0009

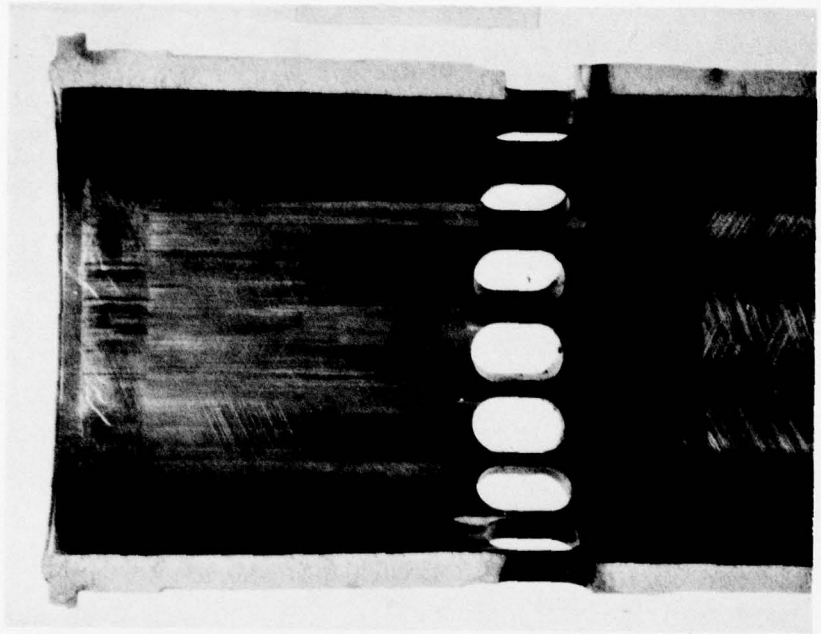
Average (All) 0.0009 IN
Average T/AT 0.0010 IN

PISTON RING GAP (IN)
TEST #11

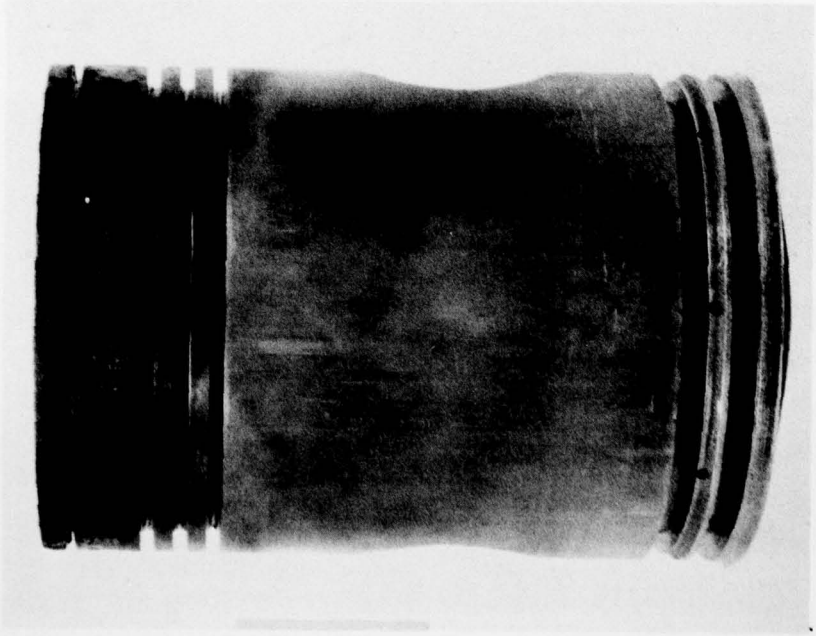
Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	0.042	0.040	0.031	0.037	0.030	0.028	0.028	0.030
	Before	.035	.040	.030	.036	.024	.023	.023	.023
	Δ	.007	---	.001	.001	.006	.005	.005	.007
2.	After	0.046	0.031	0.027	0.033	0.025	0.025	0.025	0.025
	Before	.035	.031	.027	.032	.021	.020	.021	.021
	Δ	.011	---	---	.001	.004	.005	.004	.004
3.	After	0.038	0.029	0.028	0.028	0.028	0.028	0.028	0.028
	Before	.031	0.029	.028	.028	.023	.022	.022	.023
	Δ	.007	---	---	---	.005	.006	.006	.005

Avg F/R (#1) Wear 0.008 IN

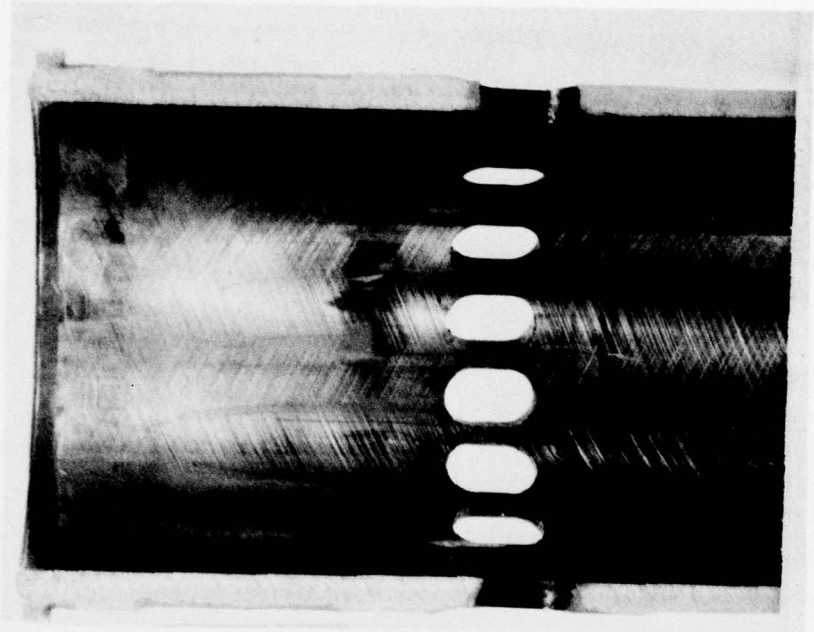
PISTON AND CYLINDER LINER CONDITION
Test #11



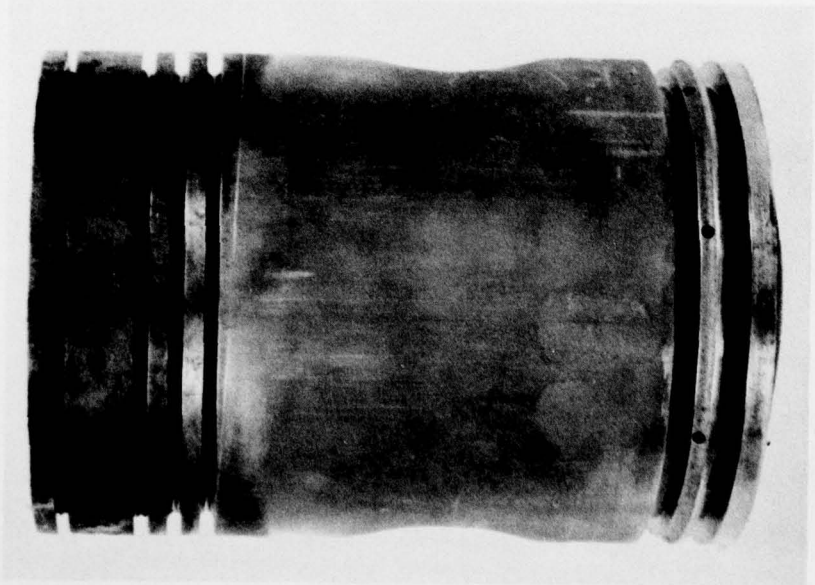
No. 3 - Antithrust Side
(worst)



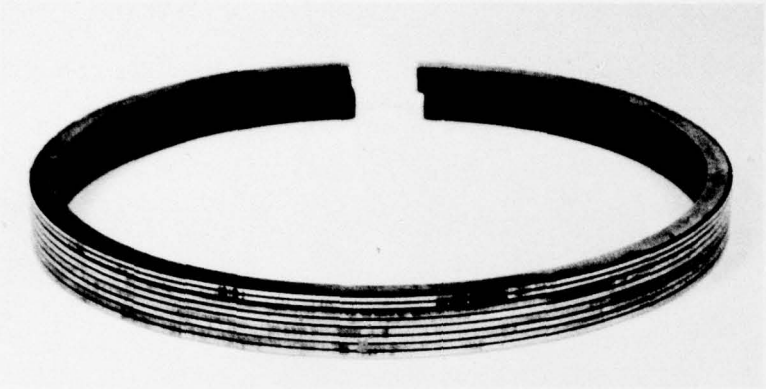
PISTON AND CYLINDER LINER CONDITION
Test #11



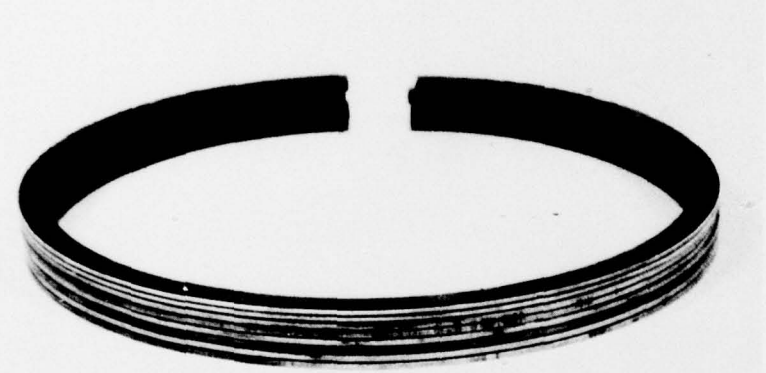
No. 2 - Antithrust Side
(best)



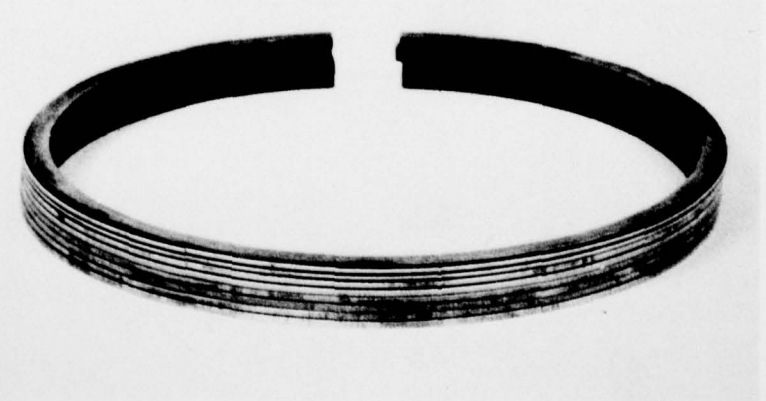
RING FACE CONDITION
Test #11



Piston - 1



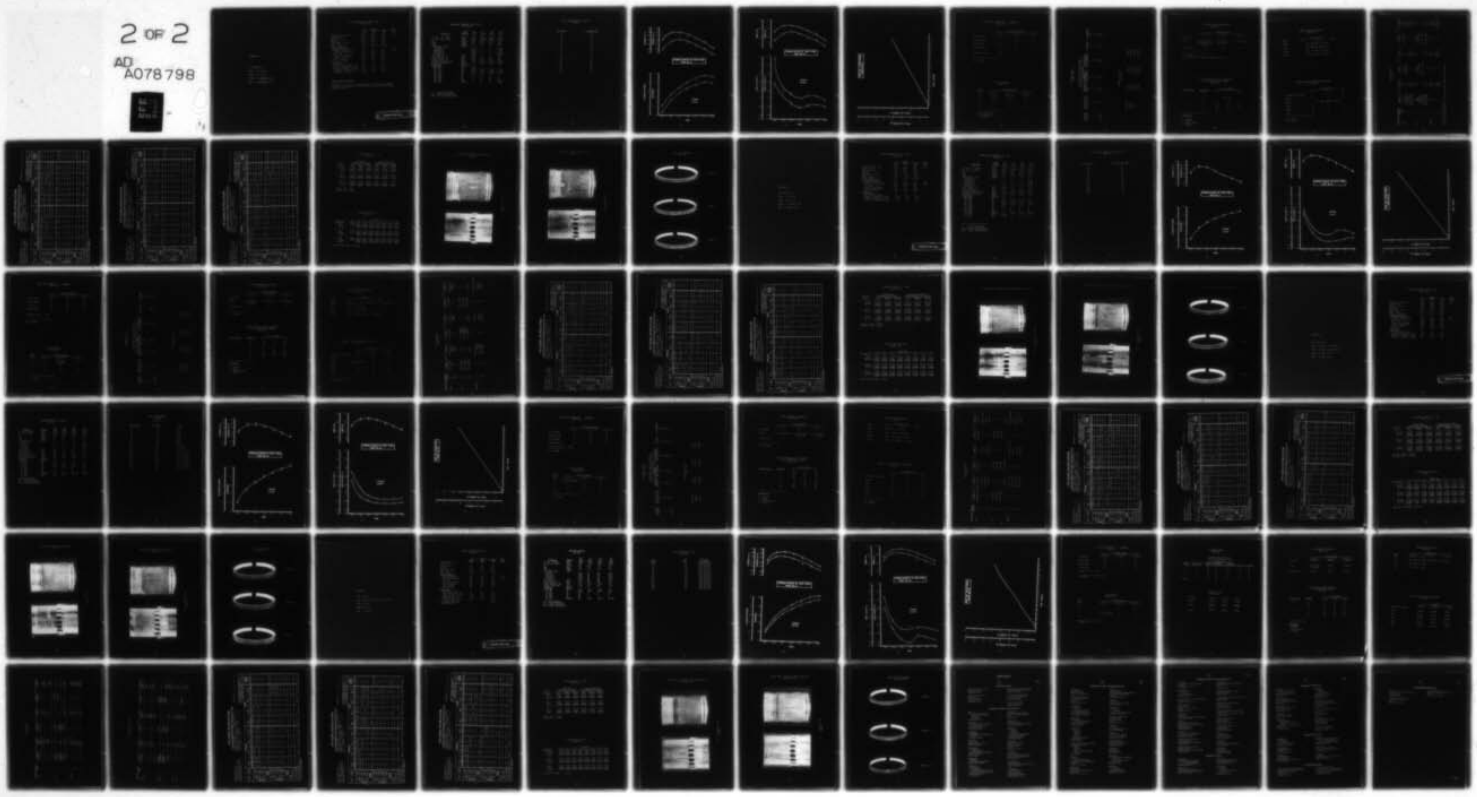
Piston - 2



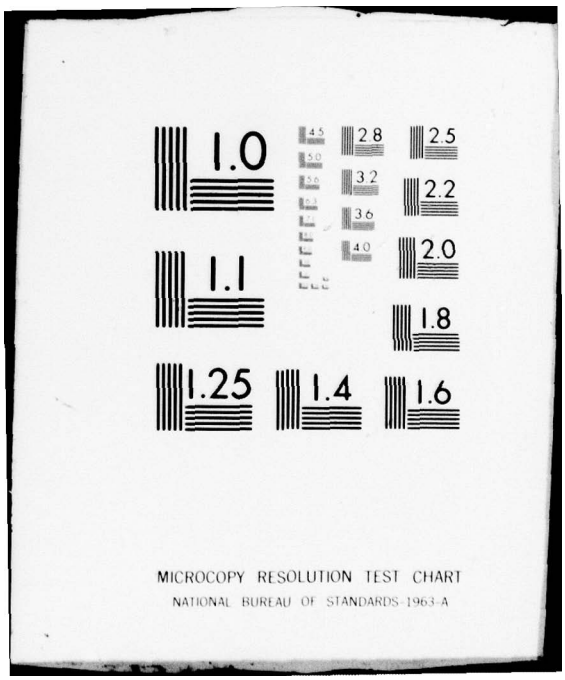
Piston - 3

AD-A078 798 SOUTHWEST RESEARCH INST SAN ANTONIO TX ARMY FUELS AN--ETC F/G 21/7
COMBATING HIGH-SULFUR FUEL EFFECTS IN A TWO-CYCLE, HIGH-SPEED U--ETC(U)
AUG 79 E A FRAME DAAK70-78-C-0001
UNCLASSIFIED AFLRL-109 NL

2 OF 2
AD A078798



END
DATE FILMED
1-80
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

APPENDIX F

3-53 TEST #13

FUEL: 1% S, DF-2

LUBE: AL-7135-L

START: 6 FEBRUARY 1978

END: 24 FEBRUARY 1978

ENGINE OPERATING DATA (AVG)
TEST #13

	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2800	2803	2801	651
Load, lbs	96	103	100	
Torque, lb-ft	168	180	175	
BHp obs	89.6	96.2	93.5	
Fuel Rate, lb/hr	39.2	41.6	40.5	
BMEP, psi	80	86	83	
BSFC lb/BHp-hr	0.420	0.448	0.433	
Temperatures, °F				
Jacket Coolant-In	197	197	197	95
Jacket Coolant-Out	205	205	205	100
Oil Sump	240	246	243	
Inlet Air (Blower)	72	91	83	
Exhaust Manifold	920	950	935	
Fuel @ Filter	86	94	90	
Fuel @ Return	138	147	143	
Pressures				
Oil Gallery, psig	44	45	44	
Blower Discharge, psig	4.3	4.4	4.4	
Intake Vacuum, in. H_2O	6.5	6.6	6.5	
Exhaust, Common, in. Hg	2.5	3.1	2.8	
Crankcase, in. H_2O	0.31	0.36	0.33	

General Observations:

Cylinder No. 2, lower half connecting rod bearing showed errosion of material. Cylinder No. 2, piston pin bushing showed distress.

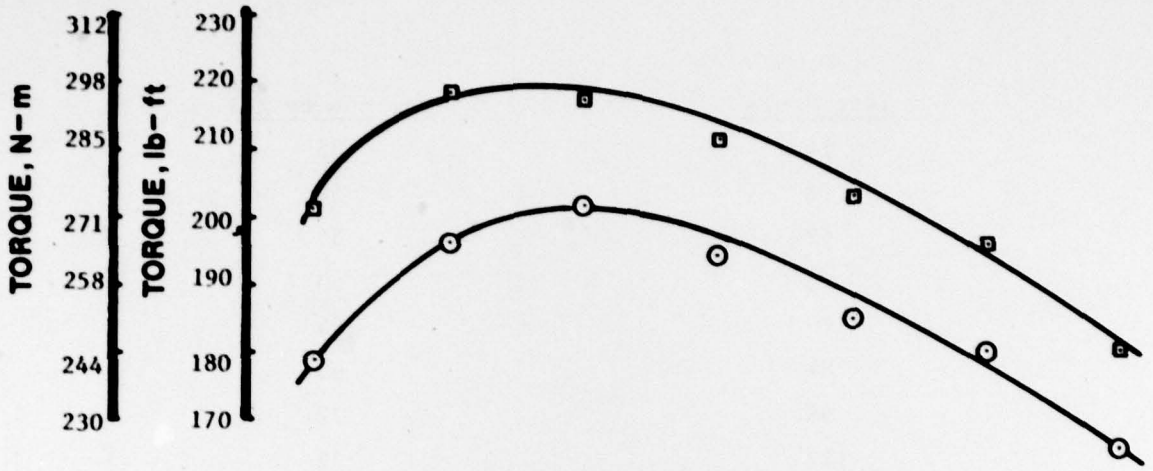
LUBRICANT ANALYSES (AL-7135-L)
TEST #13

Property	ASTM Method	New Oil	70 Hrs	140 Hrs	210 Hrs
K. Vis, cS, 40°C	D445	67.5	69.6	71.2	71.0
K. Vis, cS, 100°C	D445	9.96	10.38	10.45	10.52
VI	D2270	143	135	133	135
TAN	D664	2.5	3.3	3.5	3.6
TBN	D2896	7.9	6.5	4.7	4.6
Insolubles, wt%	D893				
Pentane A		0.03	---	---	0.04
Benzene A		0.01	---	---	0.26
Pentane B		0.01	---	---	0.03
Benzene B		0.01	---	---	0.23
API Gravity, °	D287	18.4	---	---	18.0
Pour Point, °C	D97	-34	---	---	---
Flash Point, °C	D92	227	263	265	260
Carbon Residue, wt%	D524	1.12	1.57	1.75	1.82
Sulfated Ash, wt%	D874	1.02	1.04	1.05	1.06
Elemental	Method				
Ba, ppm	AA	< 50	---	---	---
Mg, w%	AA	0.08	---	---	---
Ca, wt%	XRF	0.09	0.08	0.09	0.09
Zn, wt%	AA	0.13	0.11	0.115	0.115
Na, ppm	AA	< 10	---	---	---
Cu, ppm	AA	---	< 1	< 1	< 1
Cr, ppm	AA	---	< 1	< 1	< 1
Pb, ppm	AA	---	7	12	16
Fe, ppm	AA/XRF	---	53	74	87/95

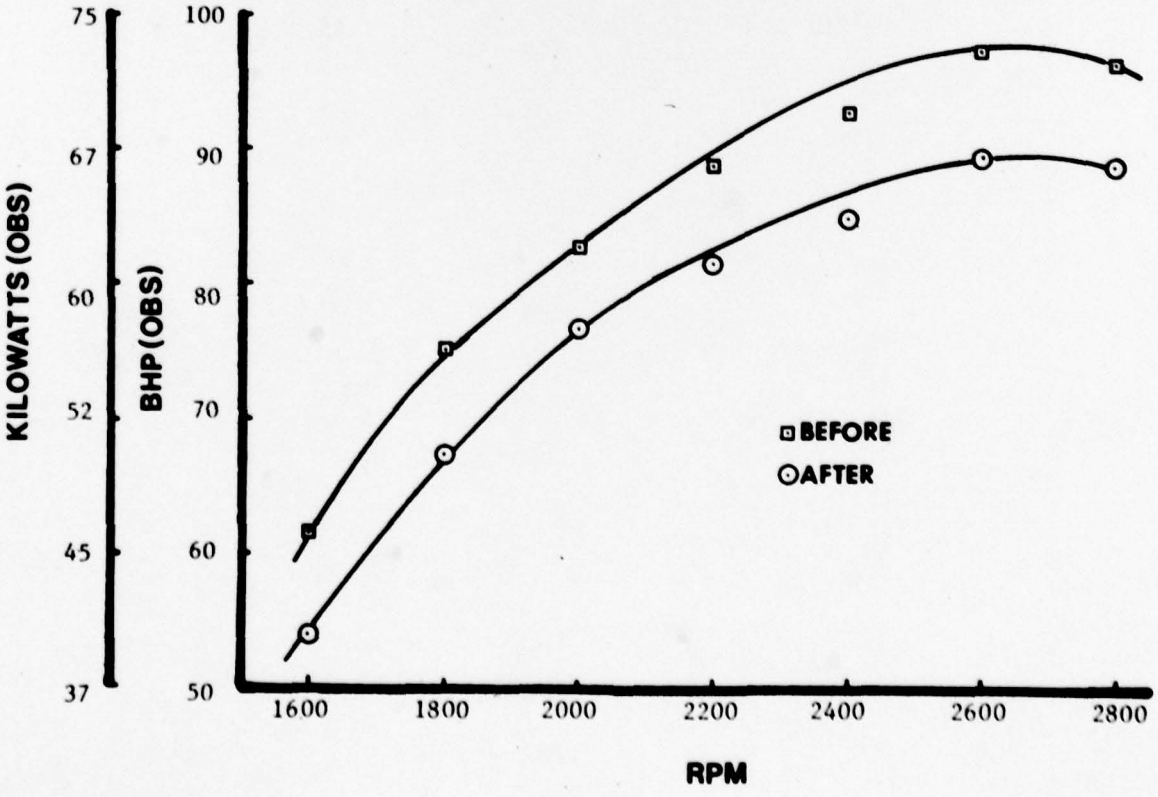
--- = Not Determined
AA = Atomic Absorption
XRF = X-Ray Fluorescence

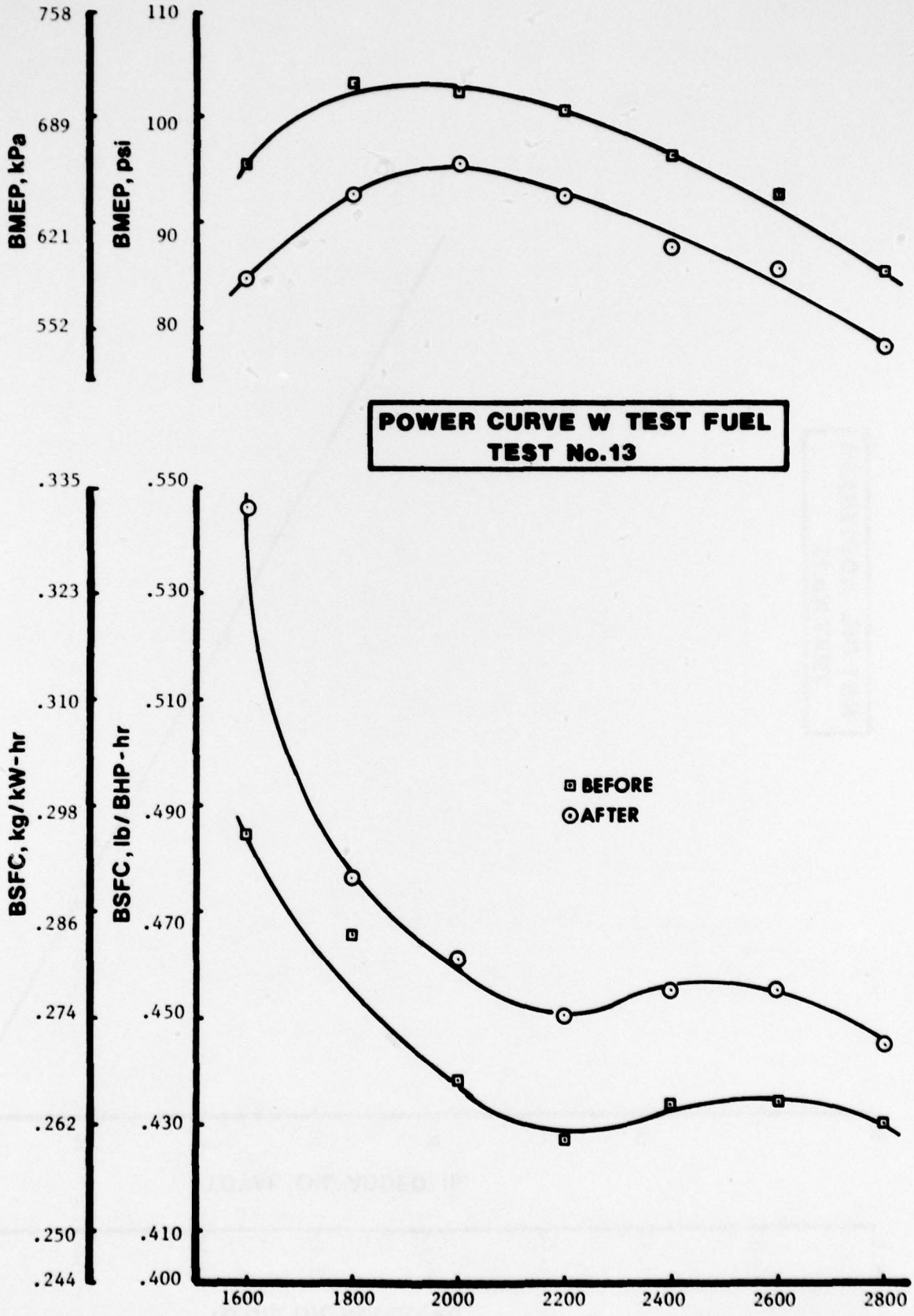
DAILY IRON CONTENT OF USED OIL
Test #13

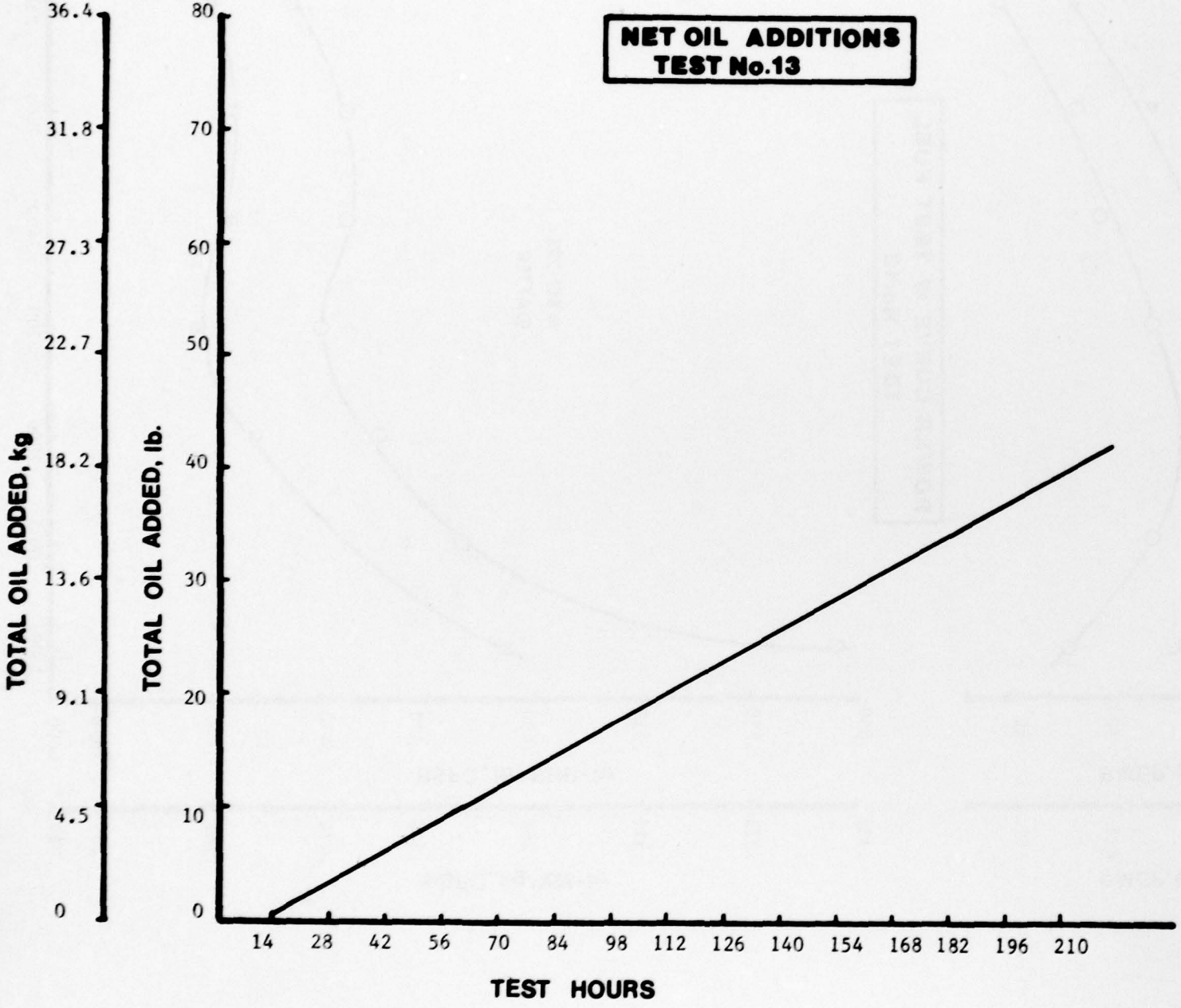
Test Hours	Fe, ppm by XRF
14	35
28	50
42	55
56	60
70	65
84	60
98	72
112	72
126	82
140	75
154	95
168	100
182	90
196	90
210	95



POWER CURVE W/ TEST FUEL
TEST No. 13




758
689
621
552
BMEP, kPa
110
100
90
80
BMEP, psi
POWER CURVE W TEST FUEL
TEST No.13
.335
.323
.310
.298
.286
.274
.262
.250
.244
BSFC, kg/kW-hr
.550
.530
.510
.490
.470
.450
.430
.410
.400
BSFC, lb/BHP-hr
BEFORE
AFTER
1600
1800
2000
2200
2400
2600
2800
RPM


NET OIL ADDITIONS
TEST No.13
TOTAL OIL ADDED, kg
36.4
31.8
27.3
22.7
18.2
13.6
9.1
4.5
0
TOTAL OIL ADDED, lb.
80
70
60
50
40
30
20
10
0
14 28 42 56 70 84 98 112 126 140 154 168 182 196 210
TEST HOURS

RING FACE CONDITION: % BURNING
TEST #13

	Cylinder Number		
	1	2	3
First Ring	10	15	5
Second Ring	5	15	15
Third Ring	15	15	5
Fourth Ring	10	15	5
Average of all	11%		

N = Normal

RING STICKING
TEST #13

Ring No.	Piston Number		
	1	2	3
1	90% HS	100% HS	100% HS
2	10% S	10% S	F
3	F	F	F
4	F	F	F

HS = Hot Stuck
S = Sluggish
F = Free

CYLINDER LINERS
TEST #13

Cylinder Liner Scuffing
Percent of Compression Ring
Travel Area

Cylinder Number	Percent Port Restriction	Percent Scuffed		% Total Area Scuffed	% Glazed	% Lacquer
		Thrust	Anti-Thrust			
1	5	20	15	17	10	90
2	10	10	75	42	3	97
3	5	15	35	25	5	95
Average	7	15	42	28	6	94

PISTON O.D. (IN)
TEST #13

Cylinder	1	2	3
Before	3.8710	3.8710	3.8710
After	3.8704	3.8707	3.8713
Δ	-0.0006	-0.0003	+0.0003

PISTON SURFACE CONDITION
TEST #13

	Piston Number		
	1	2	3
Top Land	N	N	N
Skirt	Lt. Scratches Lt. Plate Melt T-Side	Lt. to Hvy. Scratches	Lt. Scratches
Piston Pin	N	N	N

N = Normal
No. 2 piston pin bushing showing distress.

PISTON GROOVE INSIDE DIAMETER -
% RING SUPPORTING CARBON
TEST #13

Piston Ring	Quadrant	Piston Number 1	2	3
1	1 2 3 4		All 100	
2	1	10	10	0
	2	15	0	0
	3	75	5	70
	4	15	0	0

Quadrants:

1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #13

Area	Cylinder No. 1	2	3
Head	All 90% AHC, 10% soot		
Face	All 100%-9 to clean		
Tulip	All 1/2 AHC to Lacq-9		
Stem	All 1/2 AHC to Lacq-9		

EXHAUST VALVE SURFACE CONDITIONS
TEST #13

	Cylinder No. 1	2	3
Freeness in Guide	F	F	F
Head	N	N	N
Face	All some light pitting		
Seat	N	N	N
Stem	N	N	N
Tip	N	N	N

F = Free
N = Normal

RING DEPOSITS
TEST #13

Cylinder Number	Ring	1		2		3	
		CARB	LACQ	CARB	LACQ	CARB	LACQ
Top	1*	ND	ND	ND	ND	ND	ND
	2	30-AHC 70-1/2 AHC	0	85-AHC 15-1/2 AHC	0	75-1/2 AHC	10-7 15-8
	3	10-AHC 40-1/2 AHC	15-8 35-5	0	70-6 30-3	0	10-7 90-5
	4	10-1/2 AHC	90-3	0	100-4	0	100-3
ID	1	ND	ND	ND	ND	ND	ND
	2	5-RS 20-AHC 75-1/2 AHC	0	90-AHC 10-1/2 AHC	0	25-AHC 75-1/2 AHC	0
	3	20-AHC 80-1/2 AHC	0	100-1/2 AHC	0	10-1/2 AHC	90-8
	4	10-1/2 AHC	90-9	0	100-8	40-1/2 AHC	60-8
Bottom	1	ND	ND	ND	ND	ND	ND
	2	0	100-3	0	100-6	0	90-6 10-3
	3	0	20-6 80-4	0	20-4 80-3	0	10-7 80-4, 10-6
	4	0	100-4	0	100-3	0	100-2

*ND = Not Determined - Fire ring not removed from piston.

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-7135

RATER E.R. Lyons DATE 2 March 1978
LABORATORY TEST NUMBER 703-13
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1% S, DF-2

PISTON NO. 1

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	534

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	GROOVES NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	GROOVES NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	GROOVES NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	GROOVES NO. 4 DEMERIT	LANDS NO. 1 AREA-%	LANDS NO. 1 DEMERIT	LANDS NO. 2 AREA-%	LANDS NO. 2 DEMERIT	LANDS NO. 3 AREA-%	LANDS NO. 3 DEMERIT	LANDS NO. 4 AREA-%	LANDS NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00	100	100.0	90	90.0	80	80.0					90	90.0	60	60.0				
	MHC	0.75							10	7.50	20	15.00								
	MC	0.50			10	5.0	20	10.0							20	10.0				
	LC	0.25							40	10.00	80	20.00	10	2.50	20	5.0	60	15.00		
	VLC	0.15							50	7.50							40	6.00		
	CARBON RATING		100.00		95.00		90.00		25.00		25.00		92.50		75.00		21.00			
LACQUER	BL	0.100																	100	10.00
	DBrL	0.075																		
	AL	0.050																		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING																		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			100.00		95.00		90.00		25.00		25.00		92.50		75.00		21.00		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-7135

RATER E.R. Lyons DATE 2 March 1978
LABORATORY TEST NUMBER 703-13
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1% S, DF-2

PISTON NO. 2

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	488

DEPOSIT TYPE	DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	GROOVES NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	GROOVES NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	GROOVES NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	GROOVES NO. 4 DEMERIT	LANDS NO. 1 AREA-%	LANDS NO. 1 DEMERIT	LANDS NO. 2 AREA-%	LANDS NO. 2 DEMERIT	LANDS NO. 3 AREA-%	LANDS NO. 3 DEMERIT	LANDS NO. 4 AREA-%	LANDS NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON HC	1.00	100	100.0	90	90.0					10	10.00	90	90.0						
CARBON MHC	0.75			10	7.50	40	30.0							75	56.25	20	15.00		
CARBON MC	0.50																		
CARBON LC	0.25					10	2.50	100	25.0	90	22.50	10	2.50			40	10.00		
CARBON VLC	0.15					50	7.50							25	3.75	40	6.00		
CARBON RATING		100.00		97.50		40.00		25.00		32.50		92.50		60.00		31.00			
LACQUER BL	0.100																	100	10.00
LACQUER DBrL	0.075																		
LACQUER AL	0.050																		
LACQUER LAL	0.025																		
LACQUER VLAL	0.010																		
LACQUER RL	0.001																		
LACQUER RATING																		10.00	
CLEAN	0																		
ZONAL RATING																			
LOCATION FACTOR																			
WEIGHTED RATING		100.00		97.50		40.00		25.00		32.50		92.50		60.00		31.00		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-7135

RATER E.R. Lyons DATE 2 March 1978
LABORATORY TEST NUMBER 703-13
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1% S, DF-2

PISTON NO. 3

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	407

DEPOSIT TYPE	DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	GROOVES NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	GROOVES NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	GROOVES NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	GROOVES NO. 4 DEMERIT	LANDS NO. 1 AREA-%	LANDS NO. 1 DEMERIT	LANDS NO. 2 AREA-%	LANDS NO. 2 DEMERIT	LANDS NO. 3 AREA-%	LANDS NO. 3 DEMERIT	LANDS NO. 4 AREA-%	LANDS NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON HC	1.00	100	100.0	85	85.0					25	25.0	80	80.0						
CARBON MHC	0.75			15	11.25														
CARBON MC	0.50					20	10.0	20	10.0	10	5.00			10	5.00				
CARBON LC	0.25					80	20.0	40	10.0	65	16.25	20	5.00						
CARBON VLC	0.15							20	3.00					75	11.25	20	3.00		
CARBON RATING		100.00		86.25		30.00		23.00		46.25		85.00		16.25		3.00			
LACQUER BL	0.100															20	2.00	100	10.00
LACQUER DBrL	0.075													15	1.125				
LACQUER AL	0.050							20	1.00							60	3.00		
LACQUER LAL	0.025																		
LACQUER VLAL	0.010																		
LACQUER RL	0.001																		
LACQUER RATING								1.00						1.125		5.00		10.00	
CLEAN	0																		
ZONAL RATING																			
LOCATION FACTOR																			
WEIGHTED RATING		100.00		86.25		30.00		24.00		46.25		85.00		17.375		8.00		10.00	

*WEIGHTED TOTAL DEPOSITS

CYLINDER LINER I.D. (IN)
TEST #13

Cylinder No.		Front/Back Parallel to Crank			Thrust/Antithrust Perpendicular to Crank		
		Top	Middle	Bottom	Top	Middle	Bottom
1.	After	3.8757	3.8760	3.8764	3.8769	3.8771	3.8767
	Before	3.8758	3.8761	3.8762	3.8762	3.8761	3.8763
	Change	-0.0001	-0.0001	0.0002	0.0007	0.0010	0.0004
2.	After	3.8759	3.8760	3.8767	3.8771	3.8768	3.8769
	Before	3.8757	3.8761	3.8734	3.8765	3.8765	3.8766
	Change	0.0002	-0.0001	0.0003	0.0006	0.0003	0.0003
3.	After	3.8760	3.8760	3.8763	3.8766	3.8771	3.8764
	Before	3.8760	3.8760	3.8762	3.8762	3.8761	3.8761
	Change	0.0000	0.0000	0.0001	0.0004	0.0010	0.0003

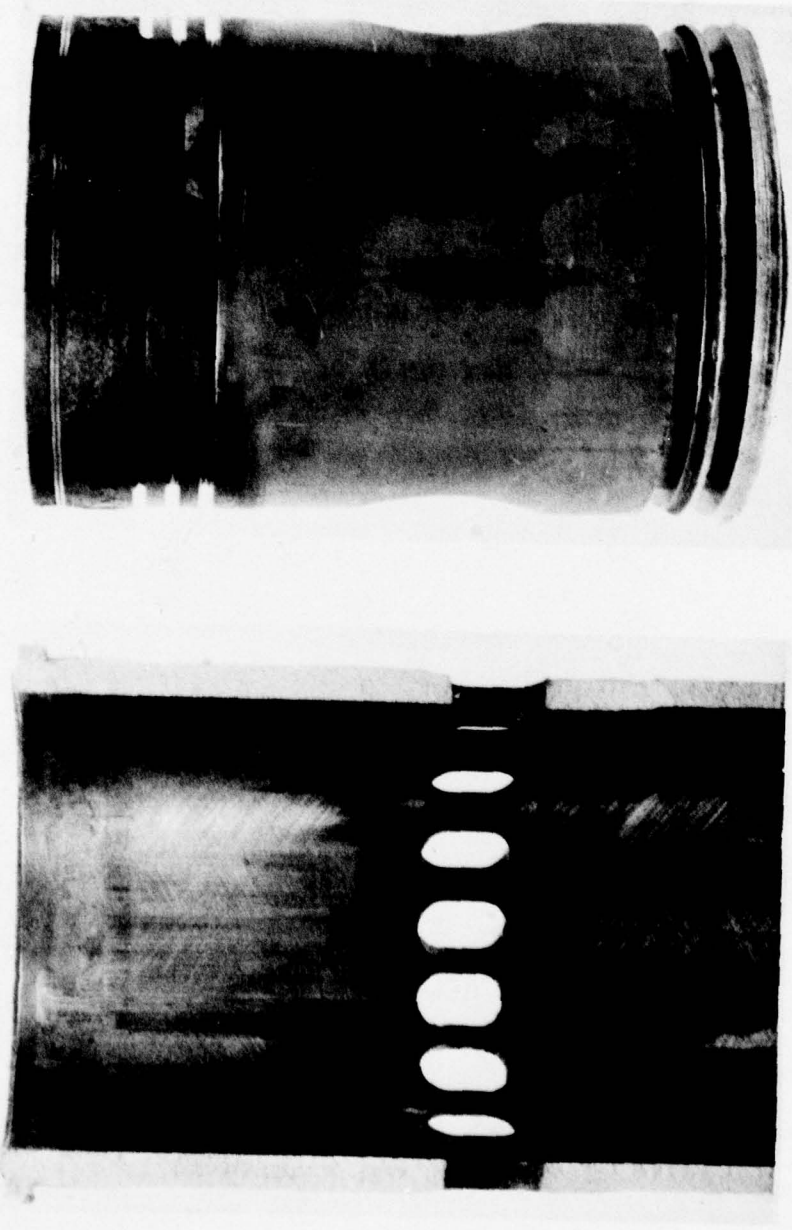
Average (All) 0.003
Average T/AT 0.006

PISTON RING GAP (IN)
TEST #13

Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	Stuck	0.032	0.026	0.036	0.026	0.026	0.026	0.026
	Before	0.031	0.031	0.026	0.035	0.023	0.023	0.023	0.023
	Change		0.001	0.000	0.001	0.003	0.003	0.003	0.003
2.	After	Stuck	0.033	0.033	0.035	0.025	0.025	0.025	0.025
	Before	0.34	0.033	0.033	0.034	0.022	0.022	0.022	0.023
	Change		0.000	0.000	0.001	0.003	0.003	0.003	0.002
3.	After	Stuck	0.029	0.027	0.027	0.025	0.025	0.026	0.026
	Before	0.031	0.029	0.027	0.027	0.023	0.022	0.023	0.023
	Change		0.000	0.000	0.000	0.002	0.003	0.003	0.003

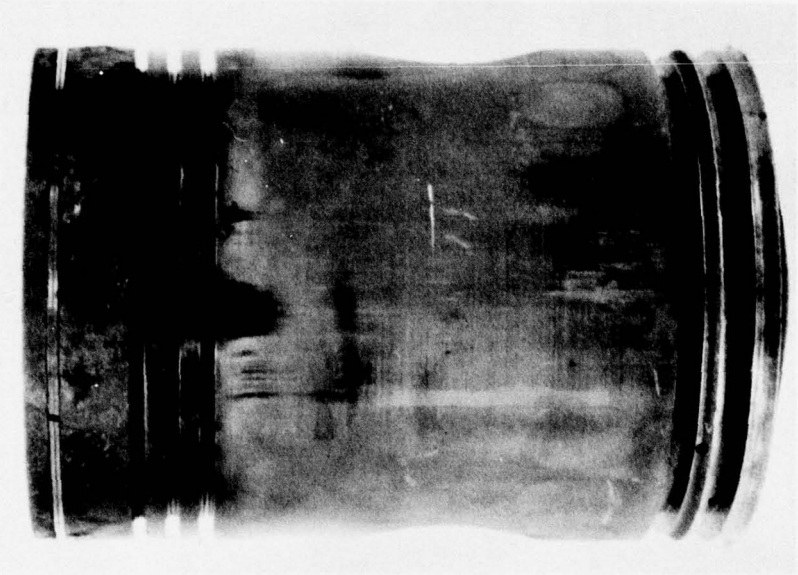
Avg F/R (#1) Wear - All Stuck

PISTON AND CYLINDER LINER CONDITION
Test #13

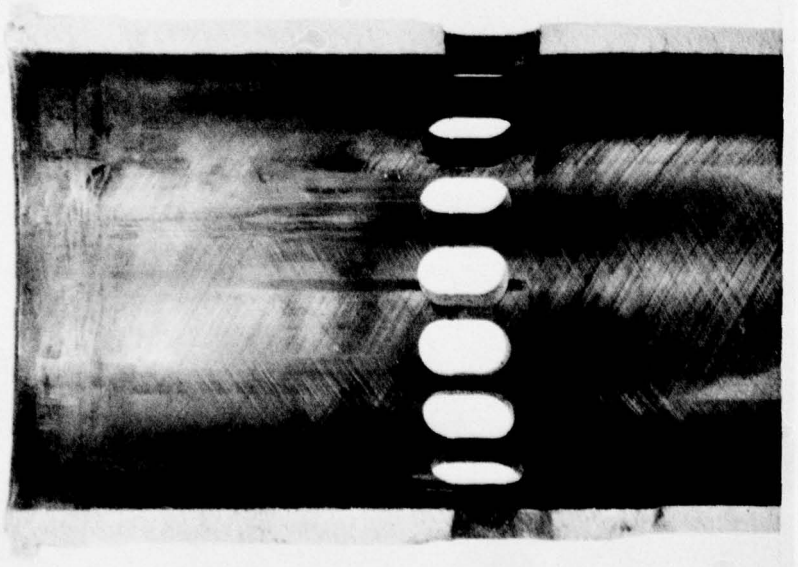


No. 2 - Antithrust Side
(worst)

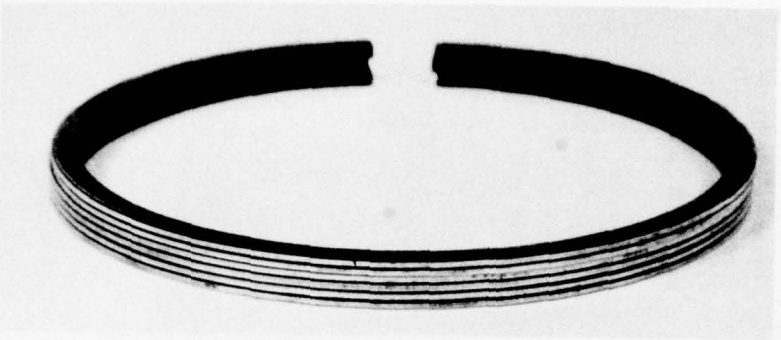
PISTON AND CYLINDER LINER CONDITION
Test #13



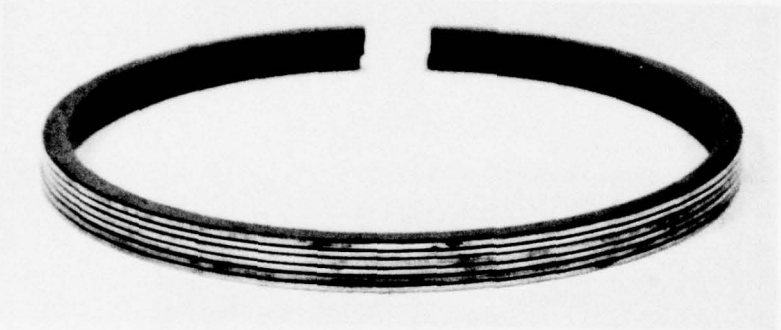
No. 2 - Thrust Side
(best)



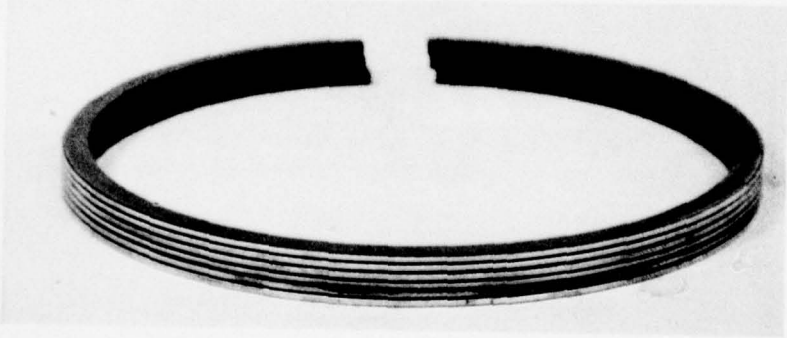
RING FACE CONDITION
Test #13



Piston - 1



Piston - 2



Piston - 3

APPENDIX G

3-53 TEST #14

FUEL: 1% S, DF-2

LUBE: AL-7287-L

START: 13 March 1978

END: 31 March 1978

ENGINE OPERATING DATA (AVG)
TEST #14

	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2798	2809	2802	650
Load, lbs	98	104	101	
Torque, lb-ft	173	180	176	
BHp obs	92	96	94	
Fuel Rate, lb/hr	38.3	43.3	40.4	
BMEP, psi	81	86	84	
BSFC lb/BHp-hr	0.417	0.455	0.430	
Temperatures, °F				
Jacket Coolant-In	194	198	197	95
Jacket Coolant-Out	202	205	205	100
Oil Sump	244	250	248	
Inlet Air (Blower)	72	96	85	
Exhaust Manifold	910	990	947	
Fuel @ Filter	72	95	89	
Pressures				
Oil Gallery, psig	44	45	44	
Blower Discharge, psig	4.0	4.4	4.2	
Intake Vacuum, in. H_2O	6.5	6.9	6.7	
Exhaust, Common, in. Hg	2.4	2.7	2.6	

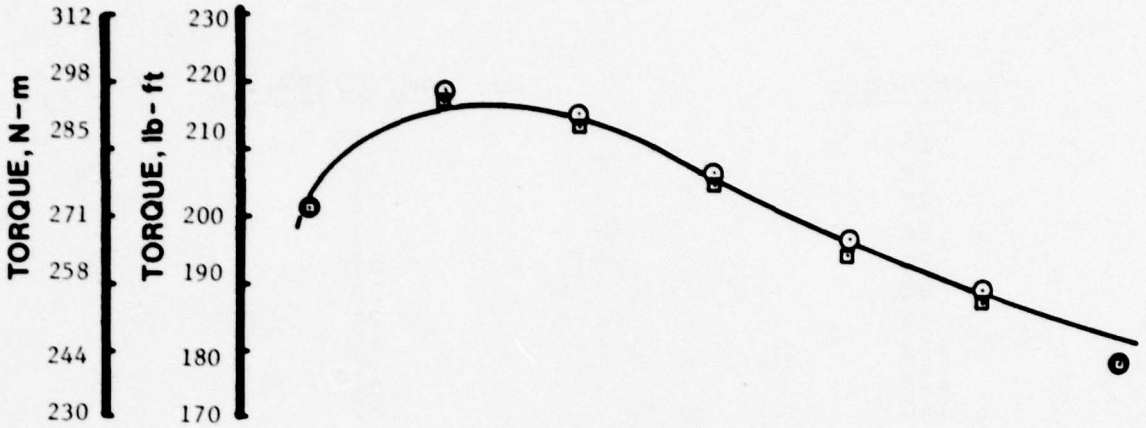
LUBRICANT ANALYSES AL-7287
TEST #14

Property	ASTM Method	New Oil	70 Hrs	140 Hrs	210 Hrs
K. Vis, cS, 40°C	D445	103.3	126.6	134.0	136.6
K. Vis, cS,100°C	D445	11.4	13.1	13.7	13.9
VI	D2270	96	96	97	98
TAN	D664	2.2	3.6	3.9	4.4
TBN	D2896	13.7	12.8	13.2	12.3
Insolubles, wt%	D893				
Pentane A		----	----	----	0.07
Benzene A		----	----	----	0.06
Pentane B		----	----	----	0.08
Benzene B		----	----	----	0.07
API Gravity, °	D287	25.5	----	----	24.2
Pour Point, °C	D97	-21	----	----	----
Flash Point, °C	D92	227	241	241	241
Carbon Residue, wt%	D524	1.82	2.74	2.69	2.91
Sulfated Ash, wt%	D874	1.63	1.96	2.08	2.13
Elemental	Method				
Ba, ppm	AA	< 50	----	----	----
Mg, ppm	AA	20	----	----	----
Ca, wt%	AA	0.40	0.50	0.52	0.54
Zn, wt%	AA	0.14	0.18	0.17	0.18
Na, ppm	AA	620	----	----	----
Cu, ppm	AA	----	5	6	6
Cr, ppm	AA	----	3	4	5
Pb, ppm	AA	----	6	6	8
Fe, ppm	XRF/AA	----	52/58	85/75	85/82
P, wt%	XRF	0.11	----	----	----
S, wt%	XRF	0.43	----	----	----

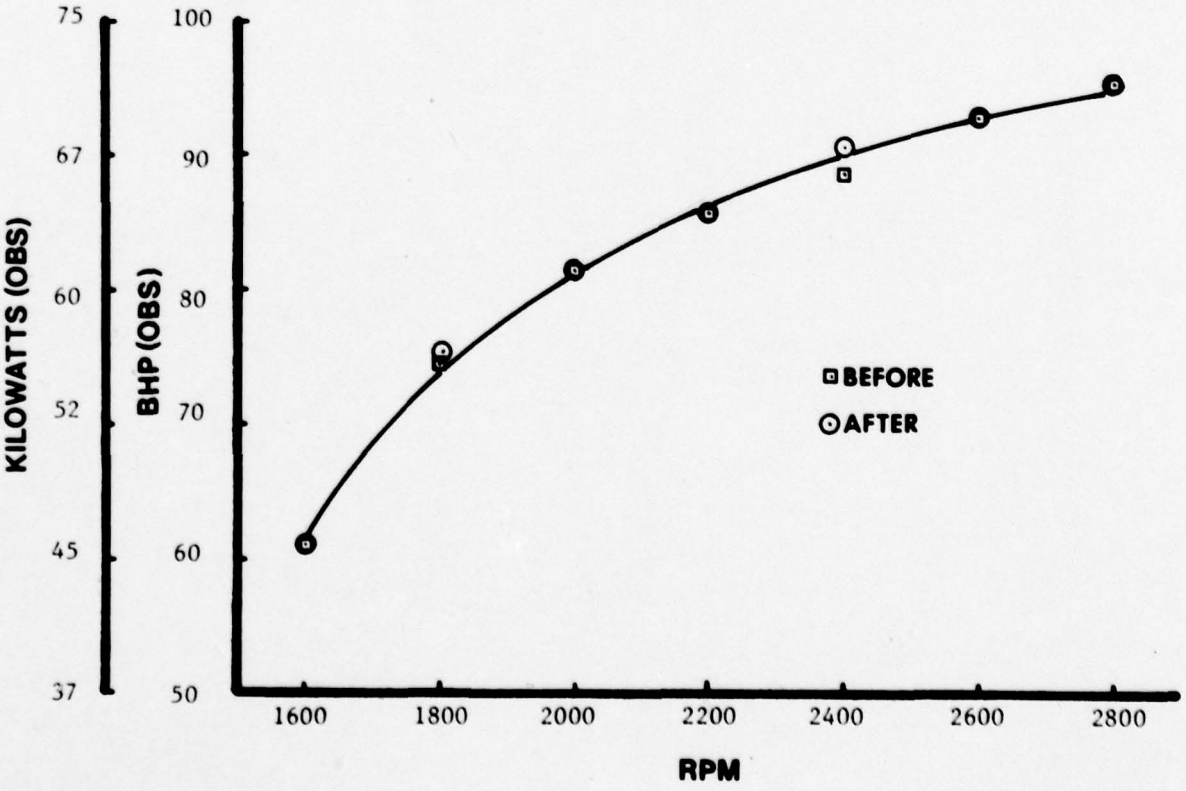
--- = Not Determined.
AA = Atomic Absorption.
XRF = X-Ray Fluorescence.

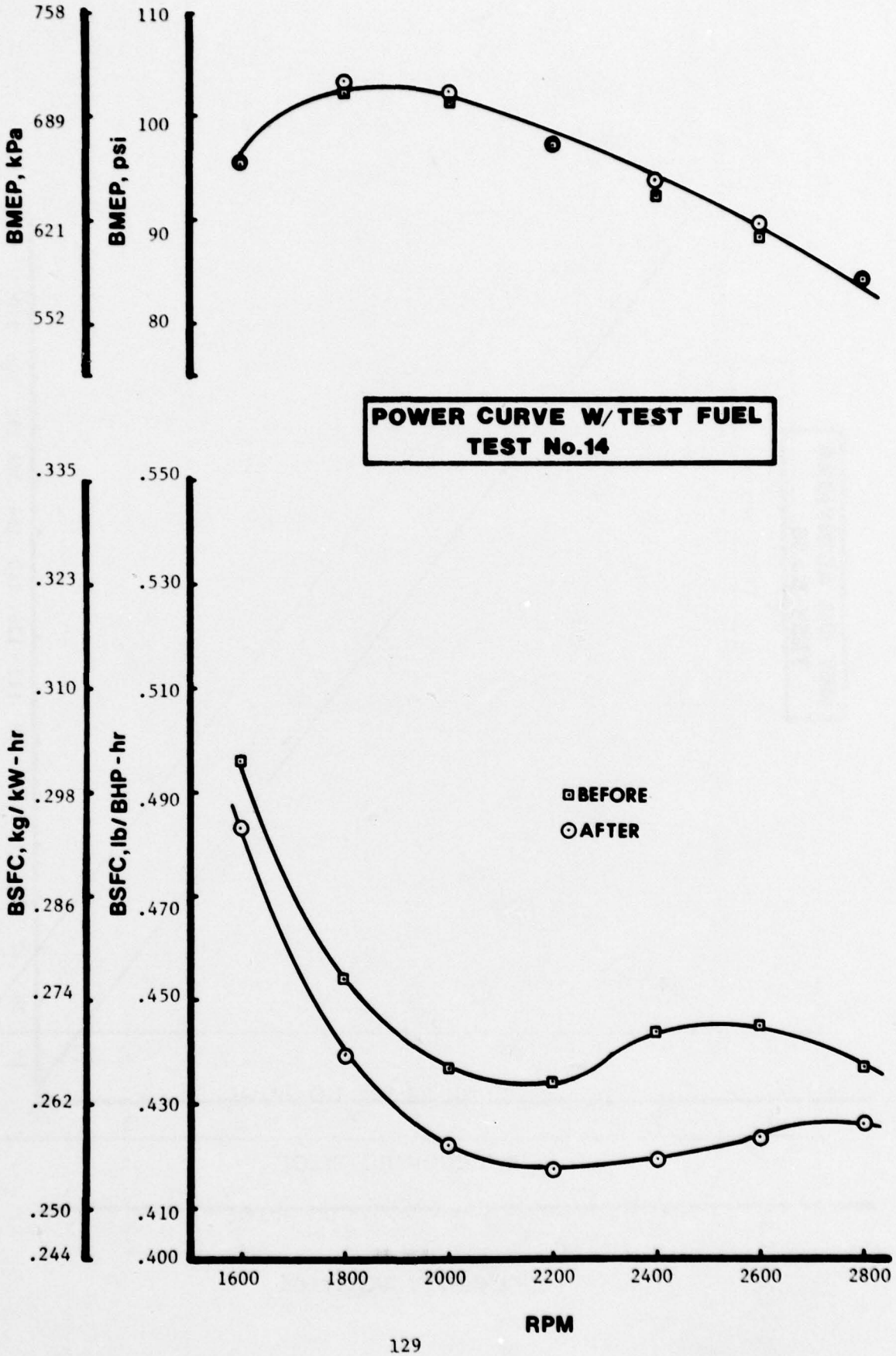
DAILY IRON CONTENT OF USED OIL
TEST #14

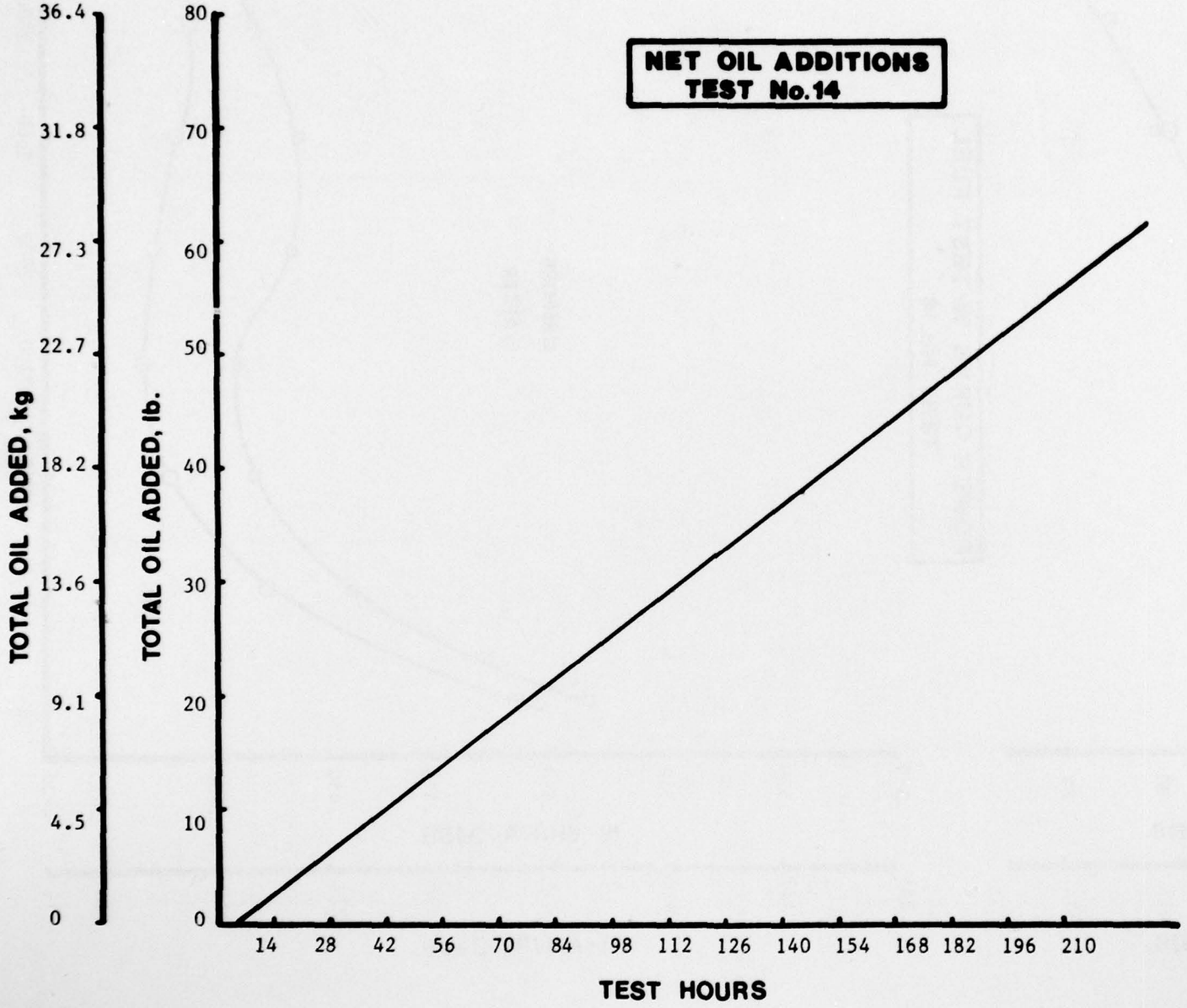
Test Hours	Fe, ppm (by KRF)
14	27
28	36
42	52
56	55
70	52
84	70
98	73
112	74
126	82
140	85
154	75
168	88
182	90
196	85
210	85



POWER CURVE W/ TEST FUEL
TEST No. 14




758
689
621
552
BMEP, kPa
110
100
90
80
BMEP, psi
POWER CURVE W/TEST FUEL
TEST No.14
.335
.323
.310
.298
.286
.274
.262
.250
.244
BSFC, kg/kW-hr
.550
.530
.510
.490
.470
.450
.430
.410
.400
BSFC, lb/BHP-hr
BEFORE
AFTER
1600
1800
2000
2200
2400
2600
2800
RPM


NET OIL ADDITIONS
TEST No.14
TOTAL OIL ADDED, kg
36.4
31.8
27.3
22.7
18.2
13.6
9.1
4.5
0
TOTAL OIL ADDED, lb.
80
70
60
50
40
30
20
10
0
14 28 42 56 70 84 98 112 126 140 154 168 182 196 210
TEST HOURS

RING FACE CONDITION: % BURNING
TEST #14

	Cylinder Number		
	1	2	3
First Ring	45	3	35
Second Ring	95	40	90
Third Ring	75	60	50
Fourth Ring	55	75	70

Average of all 58%

N = Normal

RING STICKING
TEST #14

Ring No.	Piston Number		
	1	2	3
1	F	30% cold stuck	F
2	F	F	F
3	F	F	F
4	F	F	F

F = Free

CYLINDER LINERS
TEST #14

Cylinder Liner Scuffing
Percent of Compression Ring
Travel Area

Cylinder Number	Percent Port Restriction	Percent Scuffed		% Total Area Scuffed	% Glazed	% Lacquer
		Thrust	Anti-Thrust			
1	5	15	35	25	5	95
2	1	5	40	22	5	95
3	1	5	35	20	10	90
Average	2	8	37	22	7	93

PISTON O.D. (IN)
TEST #14

Cylinder	1	2	3
Before	3.8707	3.8704	3.8705
After	3.8706	3.8704	3.8705
	0.001	0	0

PISTON SURFACE CONDITION
TEST #14

	Piston Number		
	1	2	3
Top Land	N	N	N
Skirt	Lt Scuff Lt Scratch	Lt Scratch	Lt Scratch
Piston Pin	N	N	N

N = Normal

PISTON GROOVE INSIDE DIAMETER -
% RING SUPPORTING CARBON
TEST #14

Piston Ring	Quadrant	Piston Number 1	2	3
1	1	70	0	95
	2	20	0	20
	3	0	5	85
	4	10	10	0
2	1	15	0	10
	2	20	30	90
	3	95	30	95
	4	100	0	15

Quadrants:

1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #14

Area	Cylinder No. 1	2	3
Head	All AHC to soot except valve Cy #2=20% BHC		
Face	All 8 & 9 lacquer		
Tulip	All 1/2 AHC to AHC		
Stem	All 1/2 AHC to soot & 9 lacquer		

EXHAUST VALVE SURFACE CONDITIONS
TEST #14

	Cylinder No. 1	2	3
Freeness in Guide	Free	Free	Free
Head	N	N	N
Face	Some pitting	N	N
Seat	N	N	N
Stem	N	N	N
Tip	N	N	N

N = normal

RING DEPOSITS
TEST #14

Cylinder Number		1		2		3	
	Piston	CARB	LACQ	CARB	LACQ	CARB	LACQ
Top	1	20-1/2AHC	60-8, 20-6	95-1/2AHC	5-6	95-1/2AHC	5-6
	2	0	100-8	0	80-7, 80-6	0	80-8, 20-6
	3	0	100-5	0	100-3	0	100-4
	4	0	100-3	0	100-3	0	100-3
ID	1	80-1/2AHC	20-8	50-1/2HAC, 50-AHC	0	100-1/2AHC	0
	2	60-1/2AHC	40-8	80-1/2AHC 20-AHC	0	100-1/2AHC	0
	3	100-1/2AHC	0	90 1/2AHC	10-8	100-1/2AHC	0
	4	0	100-8	0	100-8	0	100-8
Bottom	1	0	10-6,20-4, 70-2	0	5-8,95-2	0	2-8,20-4,78-2
	2	0	5-7, 95-3	0	100-3	0	100-2
	3	0	5-6, 95-3	0	100-3	0	100-3
	4	0	5-7, 95-3	0	5-6, 95-c	0	100-3

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-7287-L

RATER Lyons DATE 4-6-78
LABORATORY TEST NUMBER 703-14
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL-7289-F

PISTON NO. 1

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	367

DEPOSIT TYPE	DEPOSIT FACTOR	GROOVES NO. 1		GROOVES NO. 2		GROOVES NO. 3		GROOVES NO. 4		LANDS NO. 1		LANDS NO. 2		LANDS NO. 3		LANDS NO. 4		UNDER-CROWN	
		AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON HC	1.00	25	25.00	75	75.00			5	5.00	55	55.00	70	70.00						
CARBON MHC	0.75					15	11.25												
CARBON MC	0.50	5	2.50	25	6.25	5	2.50							25	12.50				
CARBON LC	0.25	70	17.50			80	20.00	55	13.75	40	10.00	15	3.75	40	10.00	15	3.75		
CARBON VLC	0.15							10	1.50	5	.75	10	1.50	15	2.25				
CARBON RATING		45.00		81.25		33.75		19.25		65.75		75.25		24.75		3.75			
LACQUER BL	0.100											5	.50	20	2.00	25	2.50		
LACQUER DBrL	0.075															60	4.50	100	7.50
LACQUER AL	0.050							30	1.50										
LACQUER LAL	0.025																		
LACQUER VLAL	0.010																		
LACQUER RL	0.001																		
LACQUER RATING								1.50				.50		2.00		7.00		7.50	
CLEAN	0																		
ZONAL RATING																			
LOCATION FACTOR																			
WEIGHTED RATING		45.00		81.25		33.75		20.75		65.75		75.75		26.75		10.75		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-7287-L

RATER Lyons DATE 4-6-78
LABORATORY TEST NUMBER 703-14
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL-7289-F

PISTON NO. 2

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	341

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES								LANDS								UNDER-CROWN	
			NO. 1		NO. 2		NO. 3		NO. 4		NO. 1		NO. 2		NO. 3		NO. 4			
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00	10	10.00	55	55.00					65	65.00	75	75.00						
	MHC	0.75	50	37.50																
	MC	0.50			45	22.50	40	20.00												
	LC	0.25	35	8.75							10	2.50	10	2.50	45	11.25				
	VLC	0.15	5	.75			10	1.50			20	3.00			40	6.00	5	.75		
	CARBON RATING		57.00		77.50		21.50				60.00		77.50		17.25		.75			
LACQUER	BL	0.100					10	1.00	45	4.50	5	.50	15	1.50	5	.50	5	.50		
	DBrL	0.075													10	.75			100	7.50
	AL	0.050					40	2.00	55	2.75										
	LAL	0.025															90	2.25		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING						3.00		7.25		5.50		1.50		1.25		2.75		7.50	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			57.00		77.50		24.50		7.25		66.00		79.00		18.50		3.50		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-7287-E

RATER Lyons DATE 4-6-78
LABORATORY TEST NUMBER 703-14
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL-7289-F

PISTON NO. 3

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	401

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	GROOVES NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	GROOVES NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	GROOVES NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	GROOVES NO. 4 DEMERIT	LANDS NO. 1 AREA-%	LANDS NO. 1 DEMERIT	LANDS NO. 2 AREA-%	LANDS NO. 2 DEMERIT	LANDS NO. 3 AREA-%	LANDS NO. 3 DEMERIT	LANDS NO. 4 AREA-%	LANDS NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00	60	60.00	75	75.00					80	80.00	90	90.00						
	MHC	0.75	10	7.50																
	MC	0.50	30	15.00	25	12.50	35	17.50												
	LC	0.25							10	2.50	15	3.75	5	1.25	10	2.50	5	1.25		
	VLC	0.15									5	.75	5	.75	15	2.25				
	CARBON RATING		82.50		87.50		17.50		2.50		84.50		92.00		4.75		1.25			
LACQUER	BL	0.100													75	7.50	10	1.00		
	DBrL	0.075																	100	7.50
	AL	0.050					65	3.25	90	4.50							85	4.25		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING						3.25		4.50						7.50		5.25		7.50	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			82.50		87.50		20.75		7.00		84.50		92.00		12.25		6.50		7.50	

*WEIGHTED TOTAL DEPOSITS

CYLINDER LINER I.D. (IN)
TEST #14

Cylinder No.		Front/Back Parallel to Crank Top	Middle	Bottom	Thrust/Antithrust Perpendicular to Crank Top	Middle	Bottom
1.	After	3.8767	3.8768	3.8772	3.8771	3.8774	3.8769
	Before	3.8762	3.8764	3.8766	3.8762	3.8764	3.8764
	Δ	0.0005	0.0004	0.0006	0.0009	0.0010	0.0005
2.	After	3.8763	3.8764	3.8767	3.8769	3.8769	3.8770
	Before	3.8762	3.8763	3.8765	3.8759	3.8762	3.8764
	Δ	0.0001	0.0001	0.0002	0.0010	0.0007	0.0006
3.	After	3.8763	3.8764	3.8767	3.8774	3.8776	3.8773
	Before	3.8760	3.8762	3.8765	3.8764	3.8765	3.8766
	Δ	0.0003	0.0002	0.0002	0.0010	0.0011	0.0007

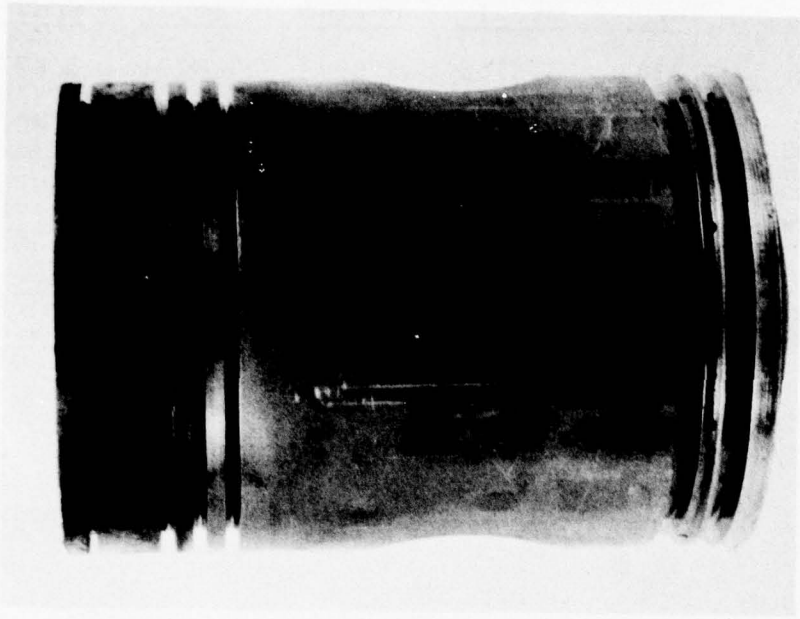
Average (All) 0.0006
Average T/AT 0.0008

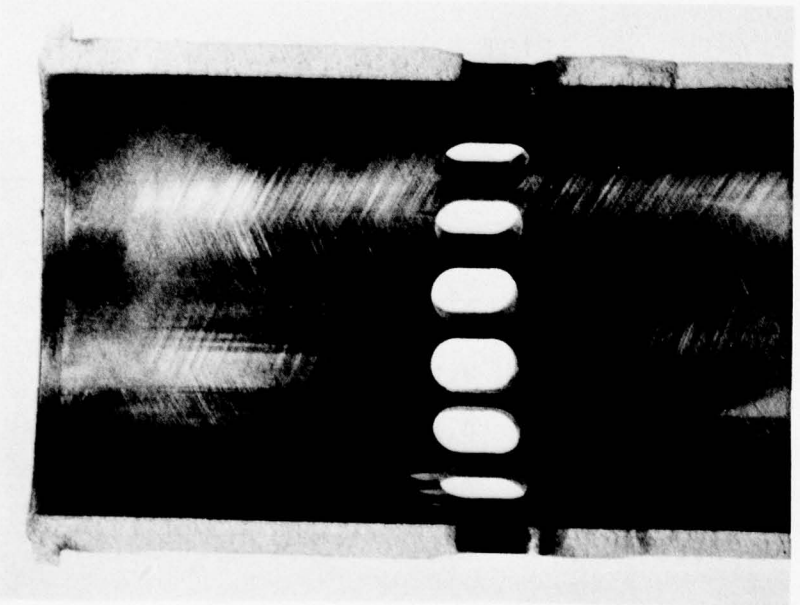
PISTON RING GAP (IN)
TEST #14

Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	0.043	0.031	0.031	0.032	0.028	0.027	0.027	0.027
	Before	0.038	0.031	0.031	0.031	0.023	0.023	0.023	0.022
	Δ	0.005	0.000	0.000	0.001	0.005	0.004	0.004	0.005
2.	After	0.036	0.035	0.031	0.031	0.027	0.027	0.027	0.027
	Before	0.033	0.035	0.031	0.031	0.022	0.023	0.022	0.023
	Δ	0.003	0.000	0.000	0.000	0.005	0.004	0.005	0.004
3.	After	0.041	0.028	0.031	0.023	0.025	0.025	0.025	0.025
	Before	0.036	0.028	0.031	0.023	0.021	0.022	0.022	0.022
	Δ	0.005	0.000	0.000	0.000	0.004	0.003	0.003	0.003

Avg F/R (#1) Wear 0.004

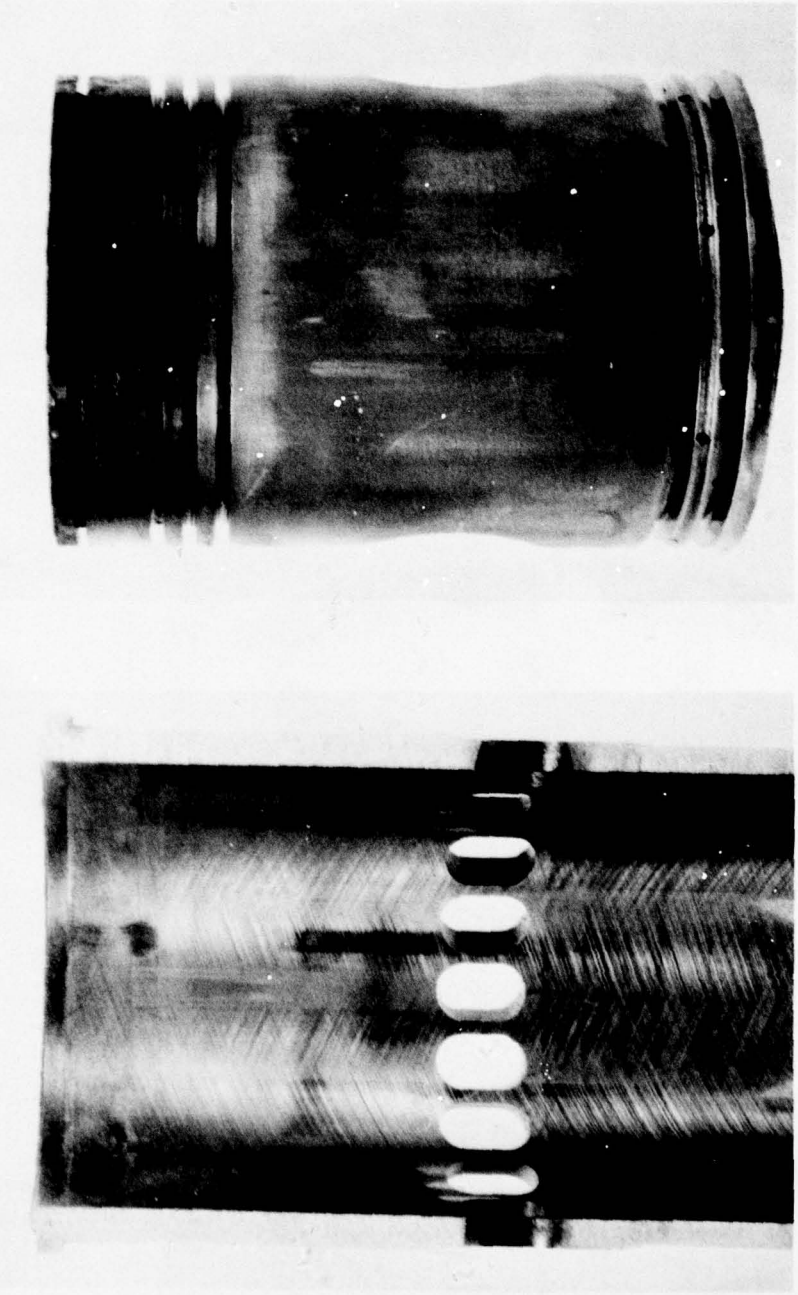
PISTON AND CYLINDER LINER CONDITION TEST #14





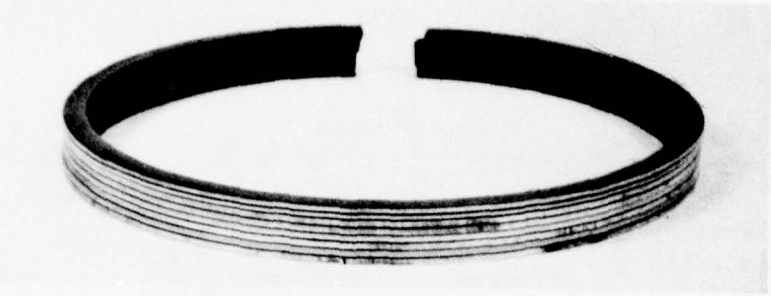
No. 2 - Anti-thrust Side
(worst)

PISTON AND CYLINDER LINER CONDITION TEST #14

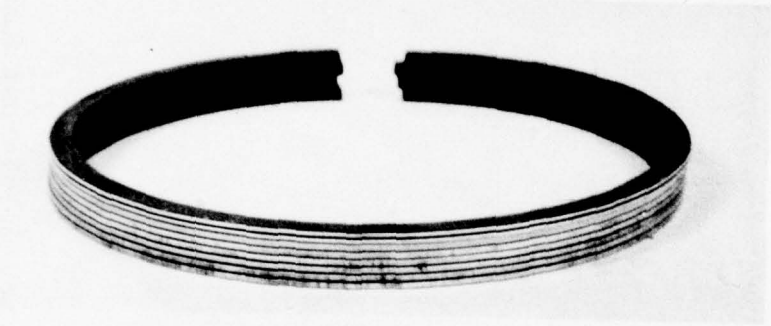


No. 3 - Thrust Side
(Best)

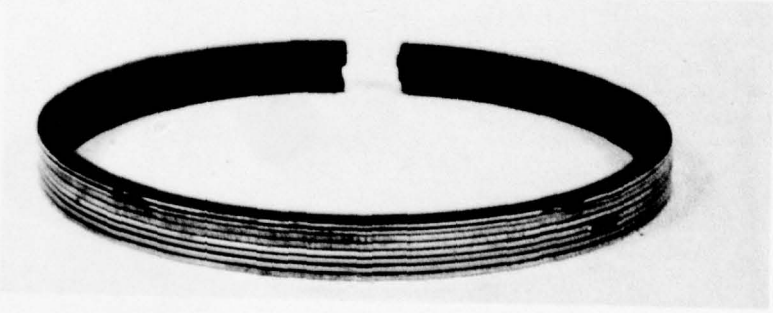
RING FACE CONDITION TEST #14



Piston - 1



Piston - 2



Piston - 3

APPENDIX H

3-53 TEST #16

FUEL: 1%S DF-2 (AL-7289-F)

LUBE: UK ER-5 (AL-6950-L)

START: 10 May 1978

END: 30 May 1978

ENGINE OPERATING DATA (AVG)
TEST #16

	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2800	2806	2802	650
Load, lbs	108	111	110	
Torque, lb-ft	189	194	192	
BHp obs	101	104	103	
Fuel Rate, lb/hr	41.9	45.7	44.0	
BMEP, psi	90	92	91	
BSFC lb/BHp-hr	0.408	0.449	0.430	
Temperatures, °F				
Jacket Coolant-In	196	198	197	95
Jacket Coolant-Out	203	205	205	100
Oil Sump	241	246	244	
Inlet Air (Blower)	78	99	89	
Exhaust Manifold	1000	1040	1017	
Fuel @ Filter	88	94	90	
Fuel Out	141	148	145	
Pressures				
Oil Gallery, psig	38	40	39	
Blower Discharge, psig	4.1	4.3	4.2	
Intake Vacuum, in. H_2O	6.6	6.8	6.7	
Exhaust, Common, in. ^{2}Hg	2.5	2.8	2.7	

LUBRICANT ANALYSES (AL-6950-L)
TEST #16

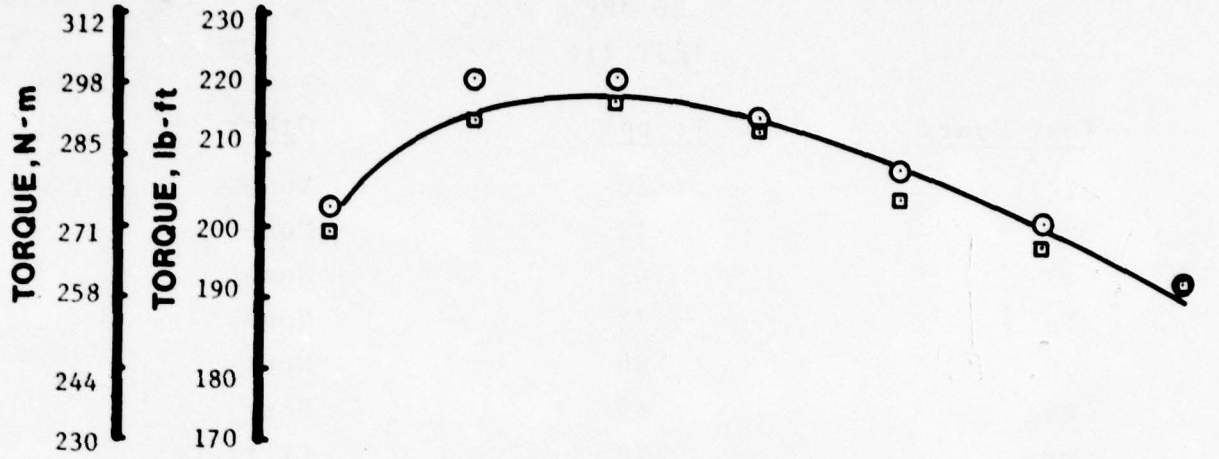
Property	Method	New Oil	70 Hrs	140 Hrs	210 Hrs
K. Vis, cS, 40°C	D445	59.67	56.00	58.85	60.09
K. Vis, cS, 100°C	D445	10.96	9.68	10.03	10.01
VI	D2270	178	158	158	153
TAN	D664	2.0	2.3	2.5	2.8
TBN	D2896	4.8	3.1	3.4	4.2
Insolubles, wt%	D893				
Pentane A		---	---	---	0.08
Benzene A		---	---	---	0.12
Pentane B		---	---	---	0.05
Benzene B		---	---	---	0.10
API Gravity, °	D287	29.1	---	---	27.1
Pour Point, °C	D97	-30	---	---	---
Flash Point, °C	D92	226	227	227	232
Carbon Residue, wt%	D524	0.56	1.36	1.64	1.74
Sulfated Ash, wt%	D874	0.73	0.85	0.95	1.00
Elemental	Method				
Ba, w%	AA	0.04	---	---	---
Mg, ppm	AA	5	---	---	---
Ca, wt%	AA	0.20	0.23	0.26	0.26
Zn, wt%	AA	0.09	0.11	0.11	0.11
Cu, ppm	AA	---	5	6	9
Cr, ppm	AA	---	5	9	11
Pb, ppm	AA	---	9	9	11
Fe, ppm	AA/XRF	---	61/80	103/136	114/149
S, wt%	XRF	0.92	---	---	---

ND = Not Determined
AA = Atomic Absorption
XRF = X-Ray Fluorescence

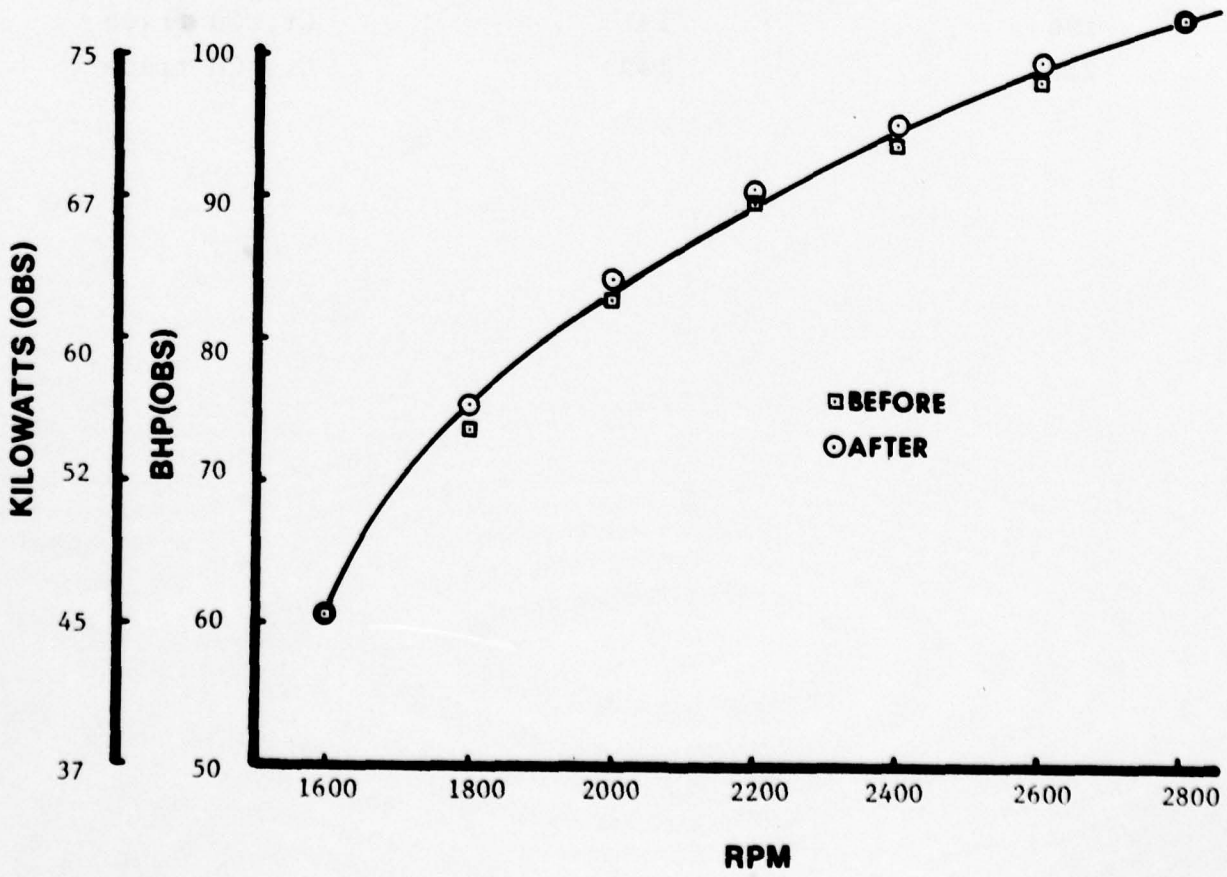
DAILY WEAR METALS
BY XRF

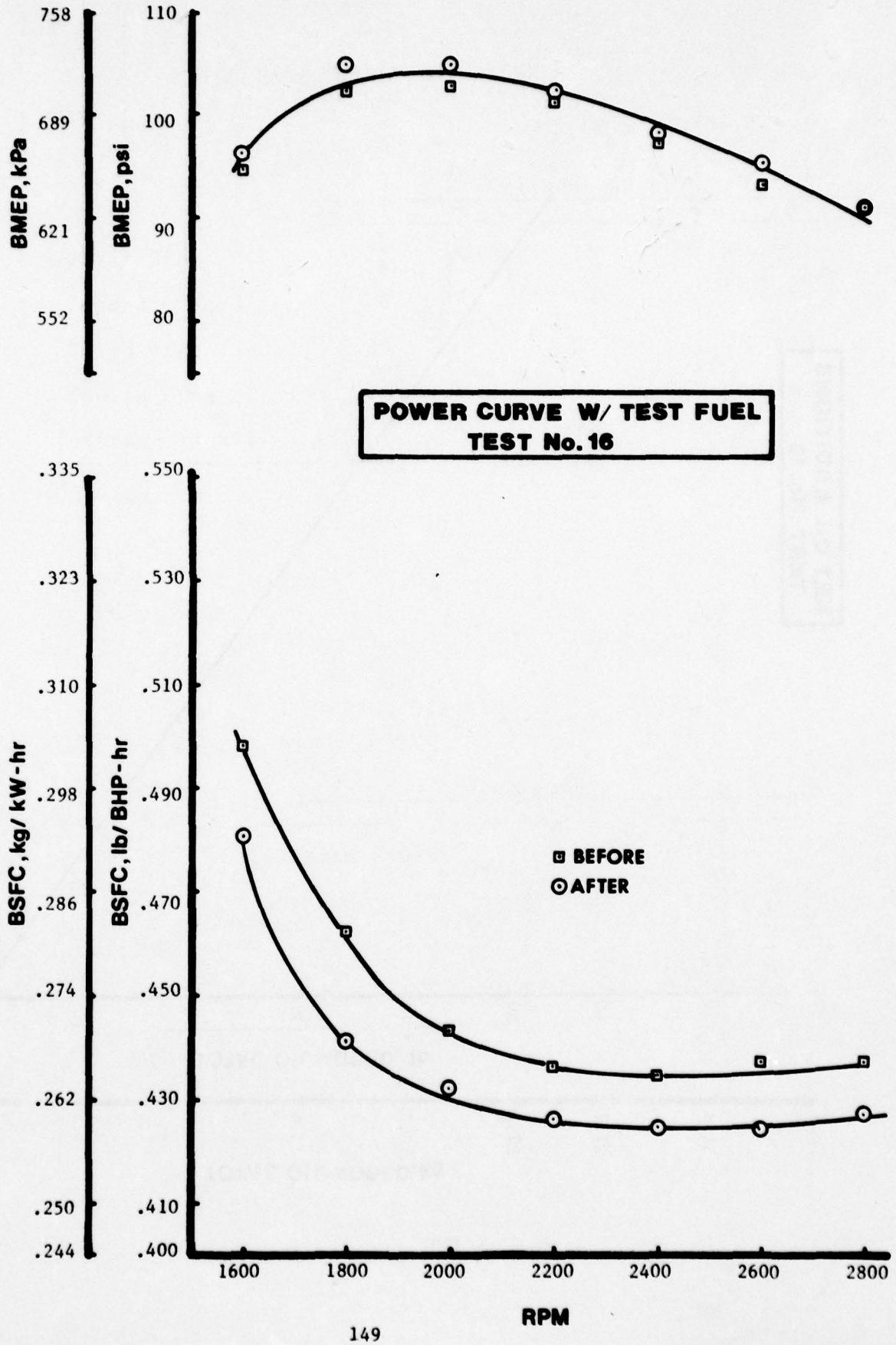
TEST #16

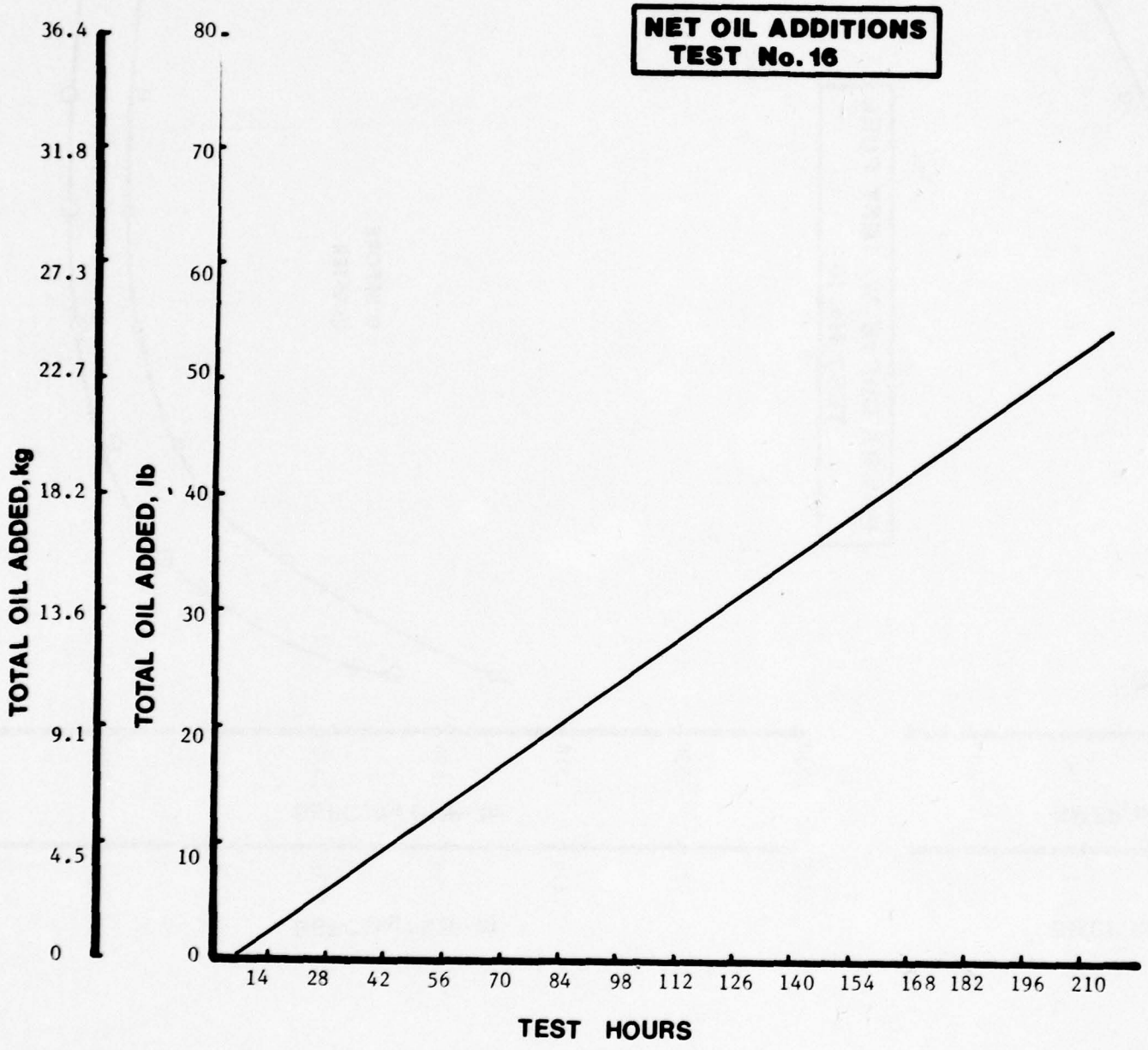
Test Hours	Fe ppm	Other
14	26	None
28	42	None
42	62	None
56	72	None
70	80	None
84	89	None
98	110	Cr trace
112	115	Cr trace
126	126	Cr, Cu trace
140	136	Cr, Cu trace
154	136	Cr, Cu trace
168	136	Cr, Cu trace
182	139	Cr, Cu trace
196	141	Cr, Cu trace
210	149	Cr, Cu trace



POWER CURVE W/ TEST FUEL
TEST No.16




758
689
621
552
BMEP, kPa
110
100
90
80
BMEP, psi
POWER CURVE W/ TEST FUEL
TEST No. 16
.335
.323
.310
.298
.286
.274
.262
.250
.244
BSFC, kg/ kW-hr
.550
.530
.510
.490
.470
.450
.430
.410
.400
BSFC, lb/ BHP-hr
BEFORE
AFTER
1600
1800
2000
2200
2400
2600
2800
RPM


NET OIL ADDITIONS
TEST No. 16
TOTAL OIL ADDED, kg
36.4
31.8
27.3
22.7
18.2
13.6
9.1
4.5
0
TOTAL OIL ADDED, lb
80
70
60
50
40
30
20
10
0
14
28
42
56
70
84
98
112
126
140
154
168
182
196
210
TEST HOURS

RING FACE CONDITION: % BURNING
TEST #16

	Cylinder Number		
	1	2	3
First Ring	2	10	35
Second Ring	5	70	95
Third Ring	25	50	80
Fourth Ring	10	35	90
Average of all	42%		

N = Normal

RING STICKING
TEST #16

Ring No.	Piston Number		
	1	2	3
1	10% cold stuck	F	F
2	F	F	F
3	F	F	F
4	F	F	F

F = Free

CYLINDER LINERS
TEST #16

Cylinder Liner Scuffing
Percent of Compression Ring
Travel Area

Cylinder Number	Percent Port Restriction	Percent Scuffed		% Total Area Scuffed	% Glazed	% Lacquer
		Thrust	Anti-Thrust			
1	5	5	15	10	15	85
2	10	30	15	23	15	85
3	15	35	90	63	10	90
Average	10	23	40	32	13	87

PISTON O.D. (IN)
TEST #16

Cylinder	1	2	3
Before	3.8710	3.8705	3.8705
After	3.8710	3.8705	3.8705
Δ	0	0	0

PISTON SURFACE CONDITION
TEST #16

	Piston Number		
	1	2	3
Top Land	N	N	N
Skirt	Lt scratches	Lt scratches V lt scuff	Lt scratches V lt scuff
Piston Pin	N	N	N

N = Normal

PISTON GROOVE INSIDE DIAMETER - % RING SUPPORTING CARBON
TEST #16

Piston Ring	Quadrant	Piston Number 1	2	3
1	1	85	5	40
	2	30	10	5
	3	100	0	0
	4	25	0	0
2	1	0	100	20
	2	85	20	25
	3	100	0	95
	4	0	25	40

Quadrants:

1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #16

Area	Cylinder No. 1	2	3
Head	ALL: 1/2 A to AHC		
Face	ALL: 100% #9 lacquer		
Tulip	ALL: #9 lacquer to AHC		
Stem	ALL: #9 lacquer to clean		

EXHAUST VALVE SURFACE CONDITIONS
TEST #16

	Cylinder No. 1	2	3
Freeness in Guide	F	F	F
Head	N	N	N
Face	N	N	N
Seat	N	N	N
Stem	N	N	N
Tip	N	N	N

F = Free
N = Normal

RING DEPOSITS
TEST #16

Cylinder Number		1		2		3	
	Piston	CARB	LACQ	CARB	LACQ	CARB	LACQ
Top	1	25-AHC,15-1/2AHC	60-8	100-AHC	0	30-1/2AHC	70-9
	2	0	100-8	0	100-8	0	90-8, 10-7
	3	0	75-8,25-3	0	100-3	0	100-4
	4	0	100-4	0	25-3,75-2	0	100-3
ID	1	100-AHC	0	100-AHC	0	100-AHC	0
	2	100-AHC	0	100-AHC	0	100-AHC	0
	3	100-1/2AHC	0	100-AHC	0	100-AHC	0
	4	0	100-8	100-1/2 AHC	0	0	100-9
Bottom	1	0	5-7, 95-3	0	20-6,25-7,55-3	0	50-5,45-4,5-8
	2	0	20-6, 80-2	0	100-2	0	100-2
	3	0	50-3, 50-2	0	100-2	0	50-4, 50-3
	4	0	85-3, 15-2	0	20-3, 80-2	0	100-3

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS _____
TEST LABORATORY _____
LUBRICANT AL-6950-L

RATER E R Lyons DATE 6-1-78
LABORATORY TEST NUMBER 703-16
STAND NO. 2 ENGINE NO. _____
FUEL AL-7289-F

PISTON NO. 1

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	336

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES								LANDS								UNDER-CROWN	
			NO. 1		NO. 2		NO. 3		NO. 4		NO. 1		NO. 2		NO. 3		NO. 4			
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00	60	60.00	50	50.00	15	15.00			30	30.00	40	40.00	30	30.00				
	MHC	0.75																		
	MC	0.50	40	20.00	25	12.50	15	7.50	10	5.00	35	17.50			10	5.00				
	LC	0.25			25	5.25	10	2.50			35	8.75	60	15.00	20	5.00	40	10.00		
	VLC	0.15																		
	CARBON RATING		80.00		67.75		25.00		5.00		56.25		55.00		13.00		10.00			
LACQUER	BL	0.100					60	6.00									10	1.00	100	10.00
	DBrL	0.075													40	3.00	10	.75		
	AL	0.050																		
	LAL	0.025							90	2.25							40	1.00		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING						6.00		2.25						3.00		2.75			
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			80.00		67.75		31.00		7.25		56.25		55.00		16.00		12.75		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS _____
TEST LABORATORY _____
LUBRICANT AL-6950-L

RATER E R Lyons DATE 6-1-78
LABORATORY TEST NUMBER 703-16
STAND NO. 2 ENGINE NO. _____
FUEL AL-7289-F

PISTON NO. 2

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	461

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES								LANDS								UNDER-CROWN	
			NO. 1		NO. 2		NO. 3		NO. 4		NO. 1		NO. 2		NO. 3		NO. 4			
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00	60	60.00	60	60.00	10	10.00	20	20.00	20	20.00	60	60.00	50	50.00				
	MHC	0.75					20	15.00												
	MC	0.50	40	20.00	40	20.00	70	35.00	10	5.00							45	22.50		
	LC	0.25							55	13.75	40	10.00	25	6.50	35	8.75	15	3.75		
	VLC	0.15									20	3.00								
	CARBON RATING		80.00		80.00		60.00		38.75		33.00		66.25		58.75		26.25			
LACQUER	BL	0.100									20	2.00	15	1.50	15	1.50	10	1.00	100	10.00
	DBrL	0.075																		
	AL	0.050							15	.75										
	LAL	0.025															30	.75		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING								.75		2.00		1.50		1.50		1.75		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			80.00		80.00		60.00		39.50		35.00		67.75		60.25		28.00		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS _____
TEST LABORATORY _____
LUBRICANT AL-6950-L

RATER E R Lyons DATE 6-1-78
LABORATORY TEST NUMBER 703-16
STAND NO. 2 ENGINE NO. _____
FUEL AL-7289-F

PISTON NO. 3

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	531

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	GROOVES NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	GROOVES NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	GROOVES NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	GROOVES NO. 4 DEMERIT	LANDS NO. 1 AREA-%	LANDS NO. 1 DEMERIT	LANDS NO. 2 AREA-%	LANDS NO. 2 DEMERIT	LANDS NO. 3 AREA-%	LANDS NO. 3 DEMERIT	LANDS NO. 4 AREA-%	LANDS NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00			100	100.0	25	25.00			10	10.00	90	90.00	90	90.00				
	MHC	0.75	100	75.00			75	56.25												
	MC	0.50							15	7.50										
	LC	0.25							40	10.00	90	22.50	10	2.50	10	2.50	100	25.00		
	VLC	0.15																		
	CARBON RATING		75.00		100.00		81.25		17.50		32.50		92.50		92.50		25.00			
LACQUER	BL	0.100							45	4.50									100	10.00
	DBrL	0.075																		
	AL	0.050																		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING								4.50										10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			75.00		100.00		81.25		22.00		32.50		92.50		92.50		25.00		10.00	

*WEIGHTED TOTAL DEPOSITS

CYLINDER LINER I.D. (IN)
TEST #16

Cylinder No.		Front/Back Parallel to Crank Top	Middle	Bottom	Thrust/Antithrust Perpendicular to Crank Top	Middle	Bottom
1.	After	3.8763	3.8765	3.8770	3.8772	3.8772	3.8771
	Before	3.8760	3.8764	3.8766	3.8762	3.8763	3.8765
	Δ	0.0003	0.0001	0.0004	0.0010	0.0009	0.0006
2.	After	3.8768	3.8765	3.8768	3.8775	3.8774	3.8771
	Before	3.8760	3.8761	3.8763	3.8761	3.8763	3.8765
	Δ	0.0008	0.0004	0.0005	0.0014	0.0011	0.0006
3.	After	3.8770	3.8766	3.8767	3.8775	3.8777	3.8773
	Before	3.8761	3.8761	3.8763	3.8760	3.8762	3.8766
	Δ	0.0009	0.0005	0.0004	0.0015	0.0015	0.0007

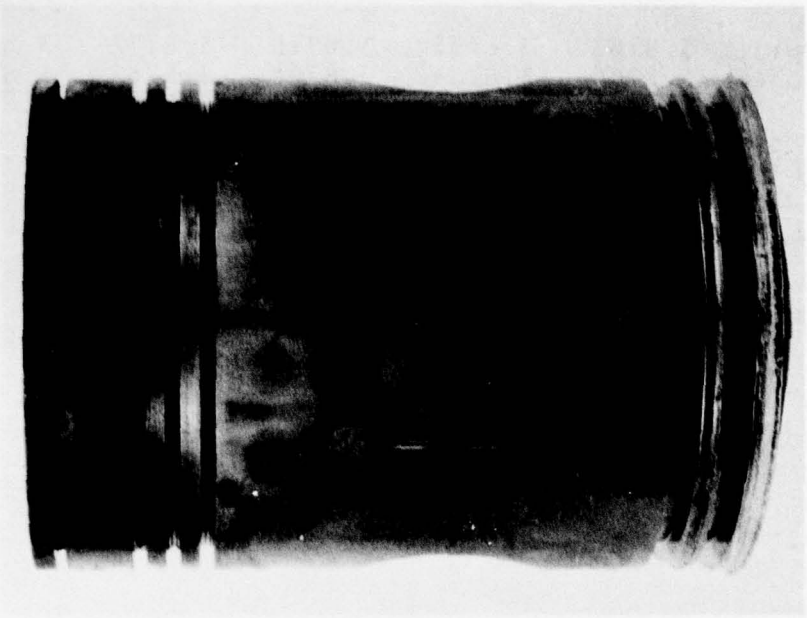
Average (All) 0.0008
Average T/AT 0.0010

PISTON RING GAP (IN)
TEST #

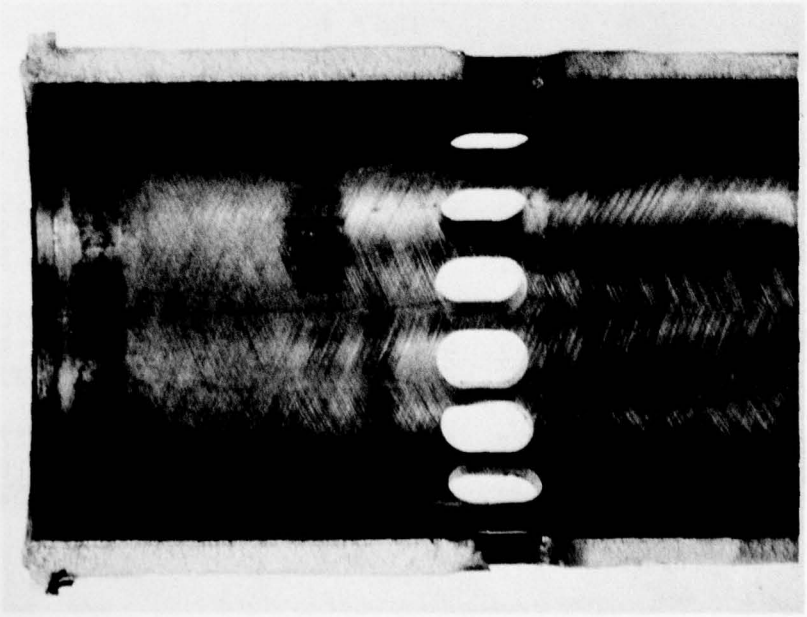
Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	0.038	0.025	0.022	0.046	0.020	0.020	0.022	0.023
	Before	0.030	0.024	0.022	0.044	0.018	0.018	0.019	0.020
	Δ	0.008	0.001	0	0.002	0.002	0.002	0.003	0.003
2.	After	0.048	0.032	0.035	0.031	0.021	0.020	0.021	0.020
	Before	0.031	0.032	0.034	0.030	0.018	0.018	0.018	0.019
	Δ	0.017	0	0.001	0.001	0.003	0.002	0.003	0.001
3.	After	0.039	0.027	0.034	0.023	0.020	0.022	0.021	0.020
	Before	0.028	0.027	0.034	0.023	0.018	0.018	0.018	0.018
	Δ	0.011	0	0	0	0.002	0.004	0.003	0.002

Avg F/R (#1) Wear 0.012 in

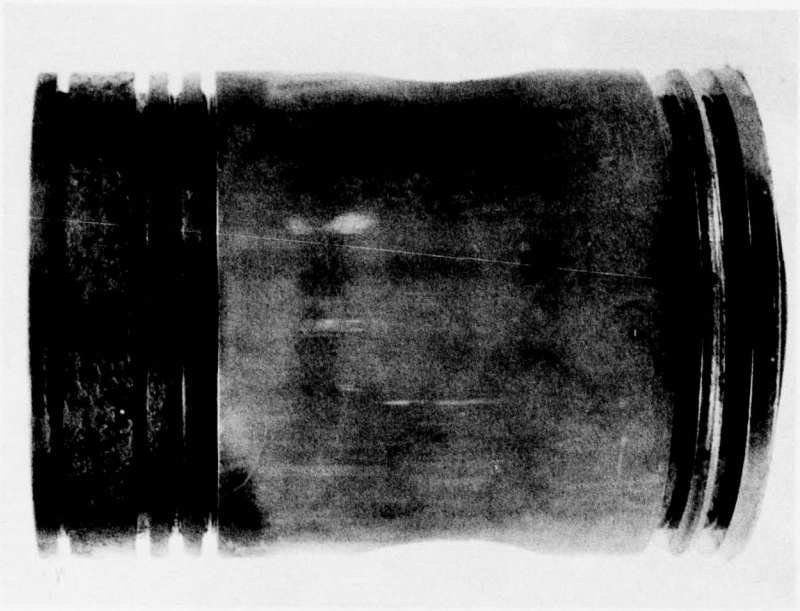
PISTON AND CYLINDER LINER CONDITION
Test #16

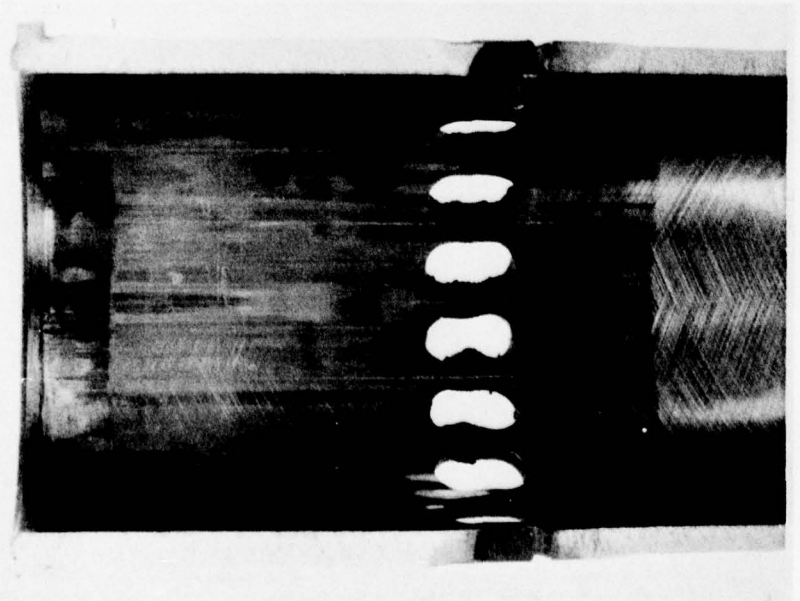


No. 1 - Thrust Side
(best)



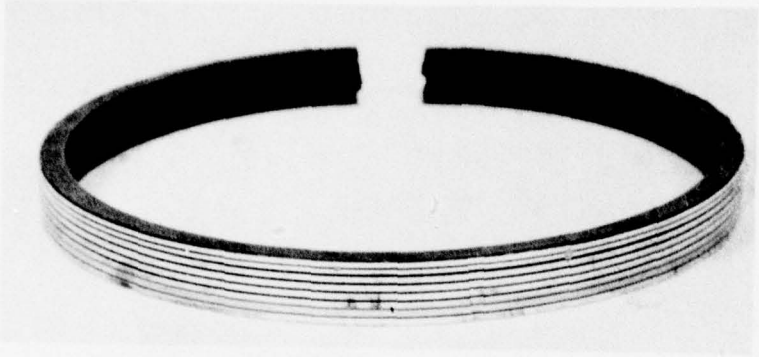
PISTON AND CYLINDER LINER CONDITION
Test #16



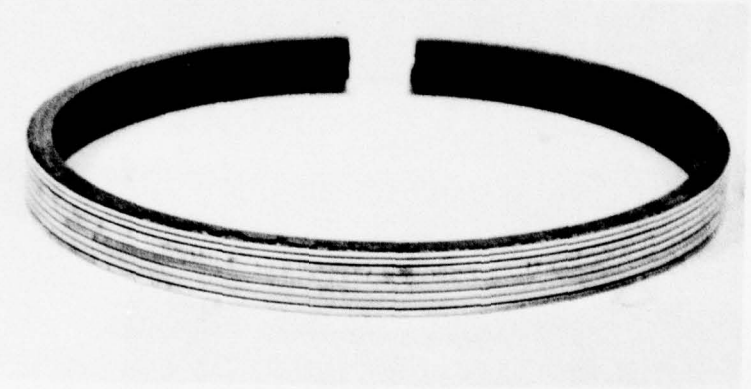


No. 3 - Antithrust Side
(worst)

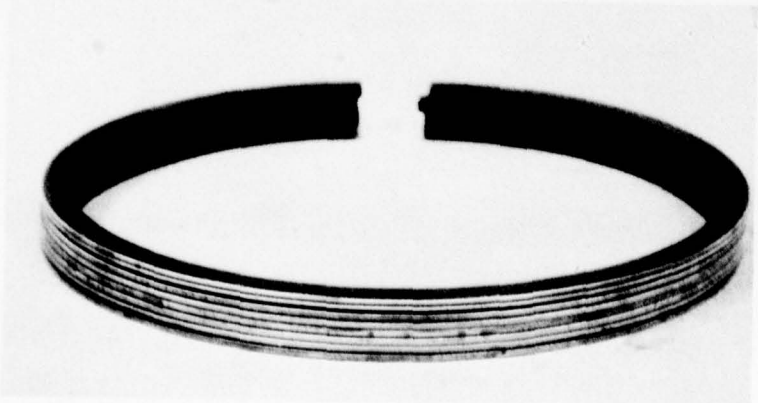
RING FACE CONDITION
Test #16



Piston - 1



Piston - 2



Piston - 3

APPENDIX I

3-53 TEST #18

FUEL: High Sulfur Fuel (1%S), AL-7766

LUBE: REO 203

START: 11 Oct 78

END: 31 Oct 78

ENGINE OPERATING DATA (AVG)
TEST #18

	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2800	2808	2802	651
Load, lbs				
Torque, lb-ft	177	196	190	
BHp obs	94	105	101	
Fuel Rate, lb/hr	40.5	43.5	42.5	
BMEP, psi	84	93	90	
BSFC lb/BHp-hr	0.408	0.444	0.420	
Temperatures, °F				
Jacket Coolant-In	196	198	197	96
Jacket Coolant-Out	205	205	205	100
Oil Sump	248	253	251	
Inlet Air (Blower)	70	90	82	
Exhaust Manifold	970	1030	1003	
Fuel @ Return	136	146	141	
Fuel @ Filter	85	94	90	
Pressures				
Oil Gallery, psig	42	43	43	
Blower Discharge, psig	4.2	4.5	4.4	
Intake Vacuum, in. H_2O	6.8	6.9	6.8	
Crankcase, in. H_2O	0.45	0.52	0.48	
Exhaust, Common, in. Hg	2.1	2.3	2.3	
Transfer Pump, psig	68	72	69	
Oil Consumption, lb.			49.6	

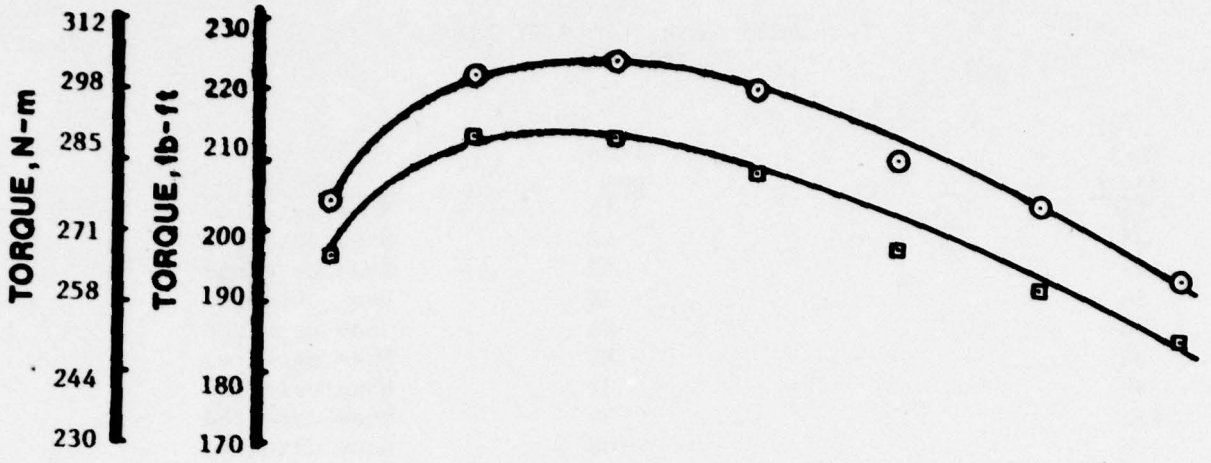
LUBRICANT ANALYSES
TEST #18

Property	Method	New Oil	70 Hrs	140 Hrs	210 Hrs
K. Vis, cS, 40°C	D445	104.6	112.3	118.7	121.0
K. Vis, cS, 100°C	D445	11.8	12.71	13.12	13.38
VI	D2270	101	106	105	106
TAN	D664	3.6	3.0	3.3	3.6
TBN	D2896	5.4	4.7	4.4	3.4
Insolubles, wt%	D893				
Pentane A		0.05	ND	ND	0.05
Benzene A		0.04	ND	ND	0.06
Pentane B		0.03	ND	ND	0.98
Benzene B		0.02	ND	ND	0.07
API Gravity, °	D287	27.5	ND	ND	26.5
Flash Point, °C	D92	241	ND	ND	252
Carbon Residue, wt%	D524	1.19	1.79	1.98	2.15
Sulfated Ash, wt%	D874	0.93	ND	ND	1.25
Elemental	Method				
Ca, wt%	AA	0.24	0.29	0.30	0.31
Zn, wt%	AA	0.09	0.13	0.13	0.13
Cu, ppm	AA	ND	5	7	8
Cr, ppm	AA	ND	4	6	8
Pb, ppm	AA	ND	6	7	8
Fe, ppm	XRF/AA	ND	85/57	103/75	121/85

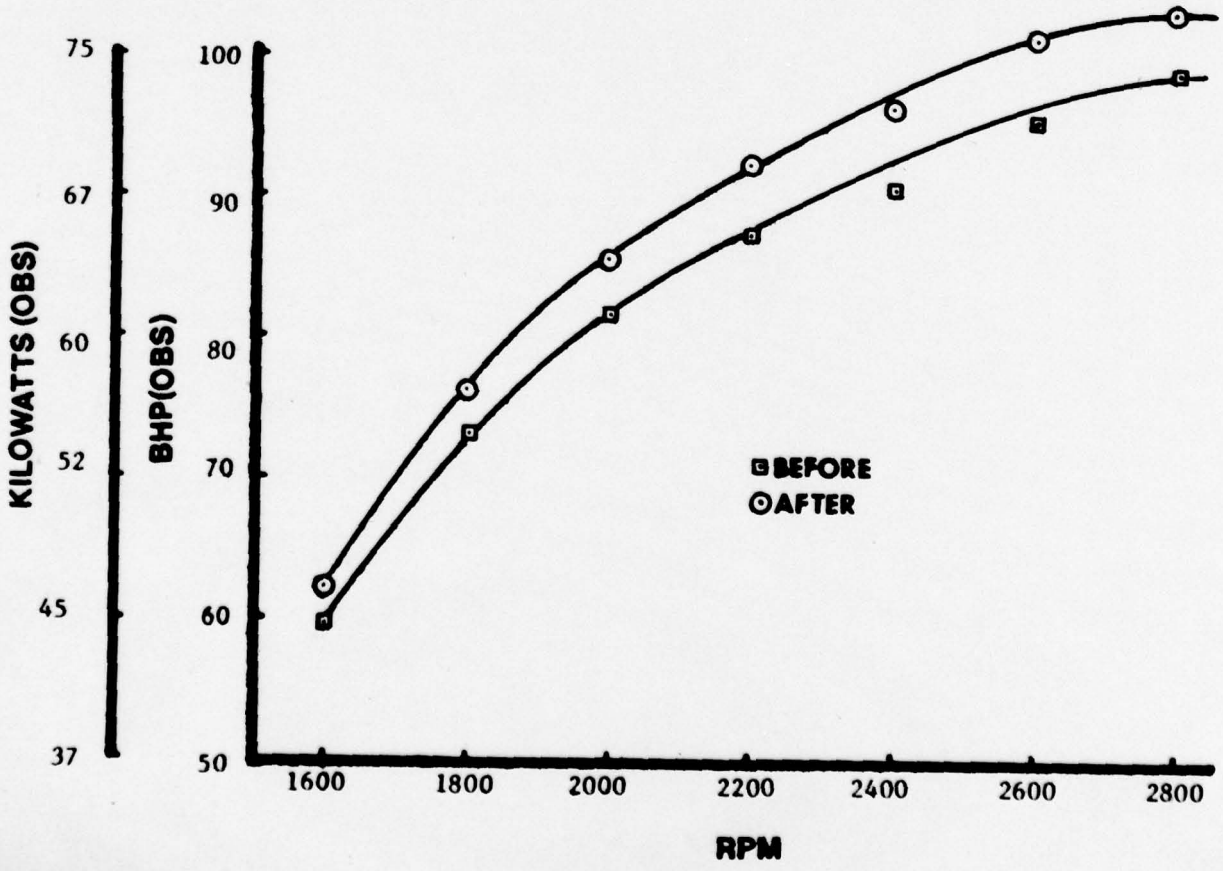
ND = Not Determined
AA = Atomic Absorption
XRF = X-Ray Fluorescence

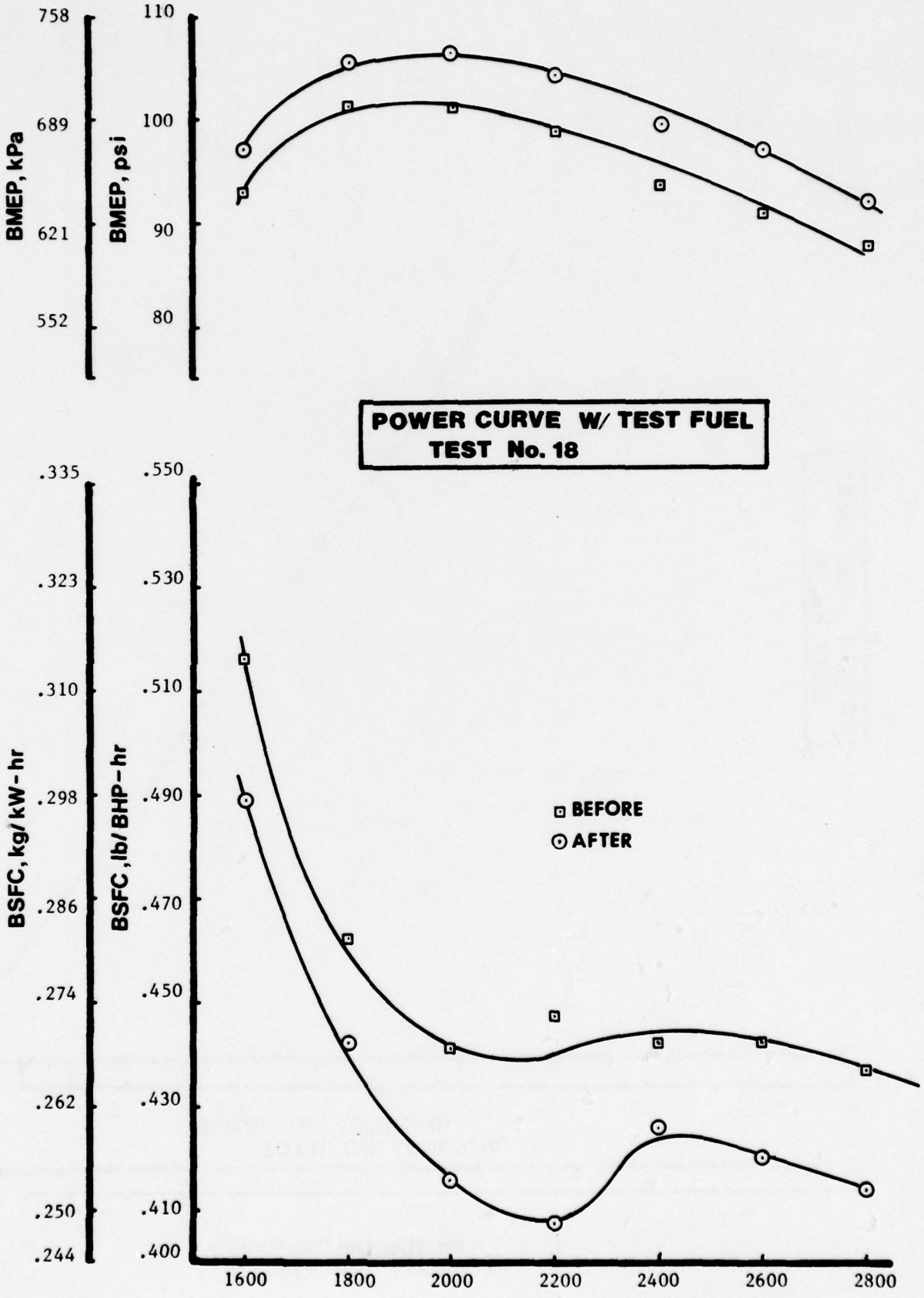
DAILY WEAR METALS BY XRF
TEST #18

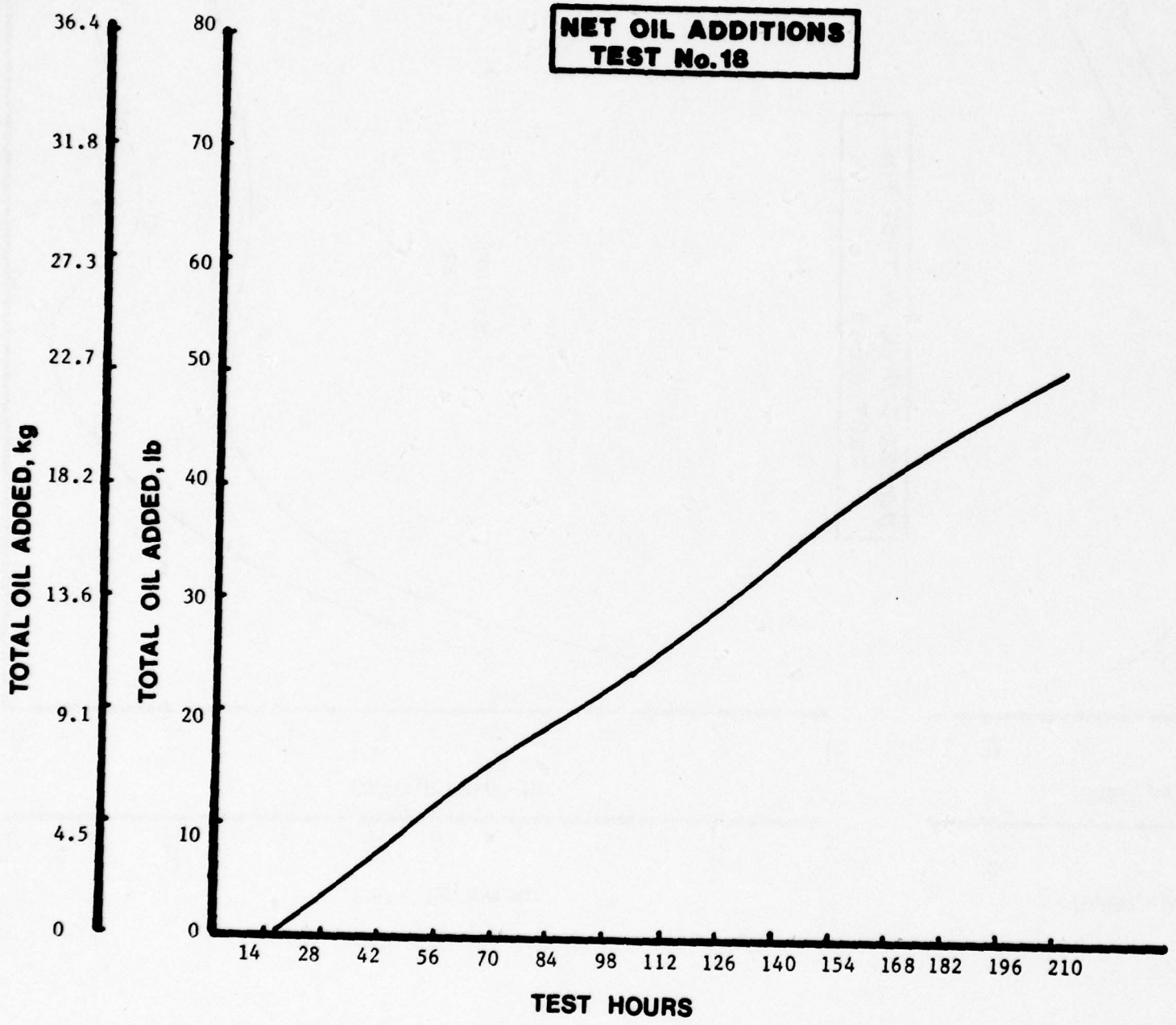
Test Hours	Iron ppm	Other Wear Elements
14	18	None detected
28	47	None detected
42	63	None detected
56	78	None detected
70	85	None detected
84	85	None detected
98	87	None detected
112	94	None detected
126	108	None detected
140	103	None detected
154	118	None detected
168	117	None detected
182	112	None detected
196	119	None detected
210	121	None detected



POWER CURVE W/ TEST FUEL
TEST No. 18




758
689
621
552
BMEP, kPa
110
100
90
80
BMEP, psi
POWER CURVE W/ TEST FUEL
TEST No. 18
.335
.323
.310
.298
.286
.274
.262
.250
.244
BSFC, kg/kW-hr
.550
.530
.510
.490
.470
.450
.430
.410
.400
BSFC, lb/BHP-hr
BEFORE
AFTER
1600
1800
2000
2200
2400
2600
2800
RPM


NET OIL ADDITIONS
TEST No.18
TOTAL OIL ADDED, kg
36.4
31.8
27.3
22.7
18.2
13.6
9.1
4.5
0
TOTAL OIL ADDED, lb
80
70
60
50
40
30
20
10
0
14
28
42
56
70
84
98
112
126
140
154
168
182
196
210
TEST HOURS

RING FACE CONDITION: % BURNING
TEST #18

	Cylinder Number		
	1	2	3
First Ring	10	10	2
Second Ring	10	5	30
Third Ring	40	2	20
Fourth Ring	80	3	10

Average of all 19%

N = Normal

RING STICKING
TEST #18

Ring No.	Piston Number		
	1	2	3
1	F	F	F
2	F	F	F
3	5% Cold Stuck	F	F
4	F	F	F

F = Free

CYLINDER LINERS
TEST #18

Cylinder Liner Scuffing
Percent of Compression Ring Travel Area

Cylinder Number	Percent Port Restriction	Percent Scuffed		% Total Area Scuffed	% Glazed	% Lacquer
		Thrust	Anti-Thrust			
1	2	10	75	43	5	95
2	2	85	40	63	15	85
3	2	20	30	25	10	90
Average	2	38	48	44	10	90

PISTON O.D. (IN)
TEST #18

Cylinder	1	2	3
Before	3.8713	3.8705	3.8700
After	3.8711	3.8705	3.8700
Change	0.0002	0.0000	0.0000

PISTON SURFACE CONDITION
TEST #18

	Piston Number		
	1	2	3
Top Land	Normal	Normal	Normal
Skirt	Sm Scratch A-T side	Normal	Normal
Piston Pin	Normal	Normal	Normal

PISTON GROOVE INSIDE DIAMETER -
% RING SUPPORTING CARBON
TEST #18

Piston Ring	Quadrant	Piston Number 1	2	3
1	1	0	0	0
	2	0	0	0
	3	0	0	0
	4	0	0	0
2	1	0	80	10
	2	95	0	30
	3	90	0	95
	4	0	40	5

Quadrants:
1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #18

Area	Cylinder No. 1	2	3
Head	All Soot to ½ AHC		
Face	Very light pitting, all 100%-4 to lt. carbon		
Tulip	All 100%-9 to ½ AHC		
Stem	All 100%-9 to clean		

EXHAUST VALVE SURFACE CONDITIONS
TEST #18

Freeness in Guide	Cylinder No. 1 F	2 F	3 F
Head	Normal	Normal	Normal
Face	Normal	Normal	Normal
Seat	Normal	Normal	Normal
Stem	Normal	Normal	Normal
Tip	Normal	Normal	Normal

RING DEPOSITS
TEST #18

Cylinder Number		1		2		3	
	Ring	CARB	LACQ	CARB	LACQ	CARB	CARB
Top	1	60-½ AHC	20-7 20-8	100-½ AHC	0	100-AHC	0
	2	0	20-9, 70-8 10-7	0	30-8 70-7	0	15-7 85-6
	3	0	10-5 90-4	0	100-7	0	100-3
	4	0	100-2	0	100-2	0	30-3 70-2
ID	1	95-½AHC	5-8	100-½AHC	0	100-½AHC	0
	2	75-AHC 25-½AHC	0 0	70-AHC 30-½AHC	0 0	100-½AHC	0
	3	100-½AHC	0	25-AHC 75-½AHC	0	0	100-9
	4	5-½AHC	95-9	0	100-9	0	100-7
Bottom	1	0	5-7, 90-2 5-9	0	20-5, 75-3 5-7	0	5-5 95-2
	2	0	5-7 95-2	0	100-2	0	15-6 85-3
	3	0	100-3	0	100-2	0	50-4 50-3
	4	0	100-2	0	100-2	0	100-2

PISTON RING GROOVE DEPOSITS
TEST # 18

Cylinder Number		1		2		3	
	Ring	CARB	LACQ	CARB	LACQ	CARB	CARB
Top of Groove	1	10-½ AHC	90-9	0	100-8	0	100-9
	2	0	100-4	0	25-8 75-4	0	100-9
	3	0	100-4	0	60-8 40-6	0	100-7
	4	0	100-4	0	30-7 70-4	0	100-5
Back of Groove	1	60-A 40-½AHC	0	100 AHC	0	80-A 20-½AHC	0
	2	30-B,40-A 30-½AHC	0	30-B 70 AHC	0	35-B 65-AHC	0
	3	100-AHC	0	30-B 70½ AHC	0	45-AHC	30-8 25-7
	4	20-AHC	80-7	0	100-9	0	45-6 55-7
Bottom of Groove	1	0	100-4	0	30-7 70-4	0	100-3
	2	0	100-5	0	45-8 55-5	0	100-3
	3	0	100-5	0	50-7 50-5	80-½AHC	20-7
	4	0	100-4	0	100-3	0	20-6 80-4

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-7219

RATER Ed Lyons DATE 11-7-78
LABORATORY TEST NUMBER 703-18
STAND NO. 2 ENGINE NO. 703
FUEL AL-7766 1%S

PISTON NO. 1

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	404

DEPOSIT TYPE	DEPOSIT FACTOR	GROOVES								LANDS								UNDER-CROWN	
		NO. 1		NO. 2		NO. 3		NO. 4		NO. 1		NO. 2		NO. 3		NO. 4			
		AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC 1.00	10	10.00	45	45.00					10	10.00	75	75.00						
	MHC 0.75	35	26.25			25	18.75	10	7.50					40	30.00				
	MC 0.50	55	27.50	55	27.50	75	37.50	5	2.50	90	45.00	15	7.00						
	LC 0.25													15	3.75				
	VLC 0.15																		
	CARBON RATING	63.75		72.50		56.25		10.00		55.00		82.50		33.75					
LACQUER	BL 0.100							85	8.50			10	1.00	45	4.50	35	3.50	100	10.00
	DBrL 0.075															15	1.125		
	AL 0.050															25	1.25		
	LAL 0.025															25	.625		
	VLAL 0.010																		
	RL 0.001																		
	LACQUER RATING							8.50				1.00		4.50		6.50		10.00	
CLEAN	0																		
ZONAL RATING																			
LOCATION FACTOR																			
WEIGHTED RATING		63.75		72.50		56.25		18.50		55.00		83.50		38.25		6.50		10.00	

*WEIGHTED TOTAL DEPOSITS

177

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-7219

RATER Ed Lyons DATE 11-7-78
LABORATORY TEST NUMBER 703-18
STAND NO. 2 ENGINE NO. 703
FUEL AL-7766 1% S

PISTON NO. 2

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	381

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	LANDS NO. 2 AREA-%	NO. 2 DEMERIT	LANDS NO. 3 AREA-%	NO. 3 DEMERIT	LANDS NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00			5	5.00	25	25.00			5	5.00	85	85.00						
	MHC	0.75	20	15.00	95	71.25														
	MC	0.50	80	40.00			75	37.50			10	5.00			35	17.50	5	2.50		
	LC	0.25									85	21.25	10	2.50			55	13.75		
	VLC	0.15							30	4.50					65	9.75	15	2.25		
	CARBON RATING		55.00		76.25		62.50		4.50		31.25		87.50		27.25		18.50			
LACQUER	BL	0.100							70	7.00			5	.50					100	10.00
	DBrL	0.075																		
	AL	0.050																		
	LAL	0.025															25	.625		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING								7.00				.50				.625		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			55.00		76.25		62.50		11.50		31.25		88.00		27.25		19.125		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-7219

RATER Ed Lyons DATE 11-7-78
LABORATORY TEST NUMBER 703-18
STAND NO. 2 ENGINE NO. 703
FUEL AL-7666

PISTON NO. 3

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	393

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00			40	40.00					30	30.00	90	90.00						
	MHC	0.75	100	75.00	60	45.00														
	MC	0.50					50	25.00			20	10.00			80	40.00				
	LC	0.25											10	2.50						
	VLC	0.15									50	7.50			20	3.00				
	CARBON RATING		75.00		85.00		25.00				47.50		92.50		43.00					
LACQUER	BL	0.100					50	5.00									10	1.00	100	10.00
	DBrL	0.075							80	6.00										
	AL	0.050							20	1.00										
	LAL	0.025															90	2.25		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING						5.00		7.00								3.25		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			75.00		85.00		30.00		7.00		47.50		92.50		43.00		3.25		10.00	

*WEIGHTED TOTAL DEPOSITS

CYLINDER LINER I.D. (IN)
TEST # 18

Cylinder No.		Front/Back Parallel to Crank			Thrust/Antithrust Perpendicular to Crank		
		Top	Middle	Bottom	Top	Middle	Bottom
1.	After	3.8763	3.8766	3.8772	3.8774	3.8777	3.8775
	Before	3.8762	3.8765	3.8767	3.8761	3.8764	3.8767
	Change	0.0001	0.0001	0.0005	0.0013	0.0013	0.0008
2.	After	3.8766	3.8766	3.8766	3.8777	3.8777	3.8770
	Before	3.8766	3.8766	3.8766	3.8762	3.8763	3.8763
	Change	0.0000	0.0000	0.0000	0.0015	0.0014	0.0007
3.	After	3.8760	3.8760	3.8761	3.8770	3.8772	3.8766
	Before	3.8760	3.8760	3.8760	3.8759	3.8759	3.8759
	Change	0.0000	0.0000	0.0001	0.0011	0.0013	0.0007

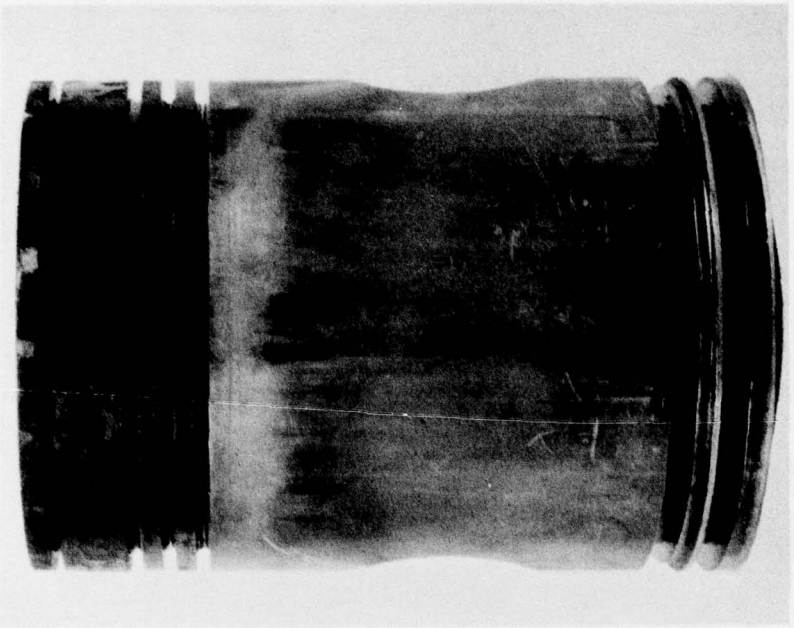
Average (All) 0.0006
Average T/AT 0.0011

PISTON RING GAP (IN)
TEST # 18

Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	0.043	0.034	0.033	0.031	0.024	0.025	0.023	0.024
	Before	0.037	0.034	0.033	0.031	0.020	0.020	0.020	0.020
	Change	0.006	0.000	0.000	0.000	0.004	0.005	0.003	0.004
2.	After	0.054	0.035	0.033	0.032	0.020	0.020	0.019	0.023
	Before	0.032	0.034	0.032	0.031	0.018	0.017	0.017	0.019
	Change	0.022	0.001	0.001	0.001	0.002	0.003	0.002	0.004
3.	After	0.030	0.032	0.034	0.031	0.020	0.022	0.020	0.026
	Before	0.025	0.032	0.033	0.030	0.017	0.018	0.017	0.022
	Change	0.005	0.000	0.001	0.001	0.003	0.004	0.003	0.004

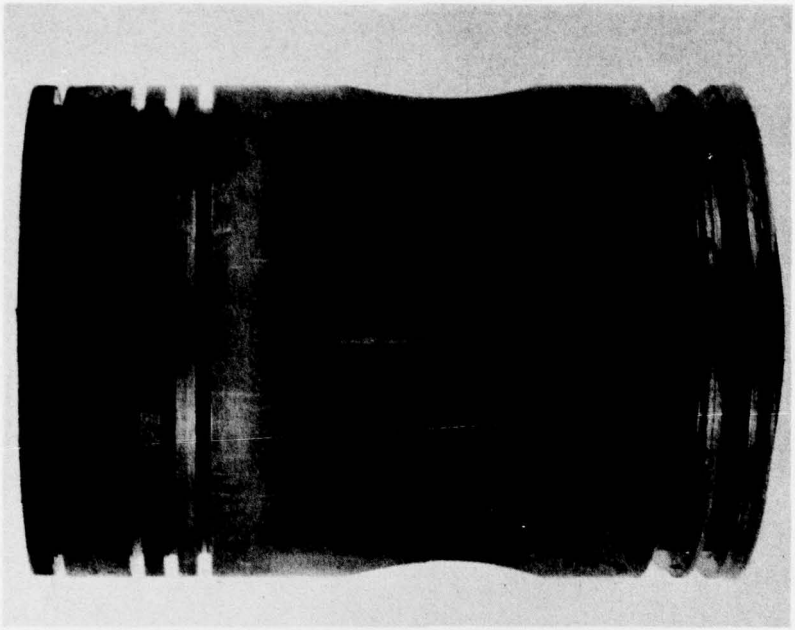
Avg F/R (#1) Wear 0.011

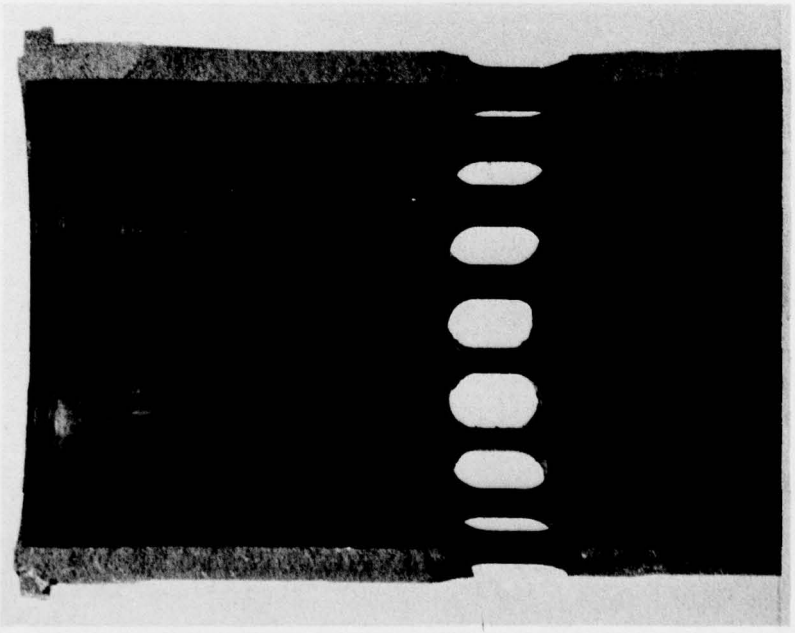
PISTON AND CYLINDER LINER CONDITION
TEST NO. 18



No. 2 - Thrust Side
(Worst)

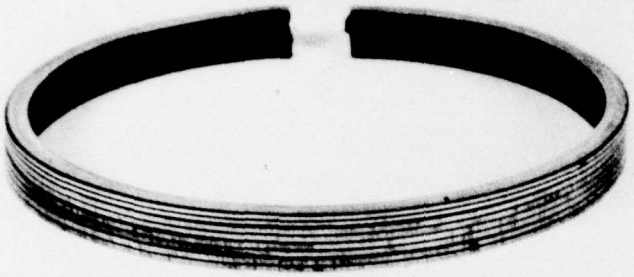
PISTON AND CYLINDER LINER CONDITION
TEST NO. 18



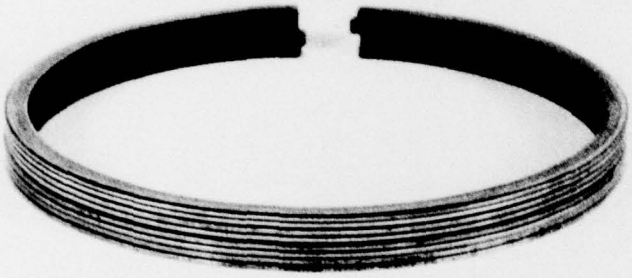


No. 1 - Thrust Side
(Best)

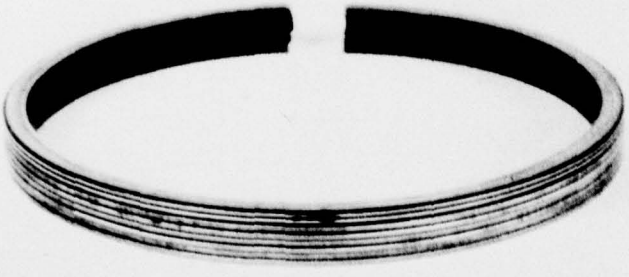
RING FACE CONDITION
Test No. 18



Piston - 1



Piston - 2



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